DOCUMENT RESUME

ED 226 240 CE 035 202

TITLE	Refrigeration and Air Conditioning Equipment, 11-9. Military Curriculum Materials for Vocational and Technical Education.
INSTITUTION	Air Force Training Command, Sheppard AFB, Tex.; Ohio State Univ., Columbus. National Center for Research in Vocational Education.
SPONS AGENCY	Office of Education (DHEW), Washington, D.C.
PUB DATE	78
NOTE	601p.; For related documents see ED 183 830-832. Several pages are marginally legible.
PUB TYPE	Guides - Classroom Use - Materials (For Learner) (051) -- Guides - Classroom Use - Guides (For Teachers) (052)
EDRS PRICE	MF03/PC25 Plus Postage.
DESCRIPTORS	*Air Conditioning; *Air Conditioning Equipment; Air Flow; Behavioral Objectives; Computation; Electric Circuits; Electricity; *Equipment Maintenance; Equipment Utilization; Instructional Materials; Job Skills; Lesson Plans; Military Personnel; Military Training; Postsecondary Education; Psychometrics; *Refrigeration; Refrigeration Mechanics; Safety; Secondary Education; *Technical Education; Thermodynamics; Workbooks
IDENTIFIERS	Military Curriculum Project; Troubleshooting

ABSTRACT

This military-developed text consists of three blocks of instructional materials for use by those studying to become refrigeration and air conditioning specialists. Covered in the individual course blocks are the following topics: refrigeration and trouble analysis, thermodynamics, and principles of refrigeration; major components and domestic and commercial refrigeration systems; and air conditioning systems (air movement, calculations, and psychometrics; direct expansion air conditioning systems; centrifugal air conditioning systems; and absorption systems). The course contains both teacher and student materials. Printed instructor materials include lesson plans and a plan of instruction detailing the steps of instruction, criterion objectives, the duration of the lessons, and support material and guidance needed. Student materials consist of study guides containing text information and workbooks containing objectives, assignments, and review exercises for each block of instruction. (MN)

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MILITARY CURRICULUM MATERIALS

The military-developed curriculum materials in this course package were selected by the National Center for Research in Vocational Education Military Curriculum Project for dissemination to the six regional Curriculum Coordination Centers and other instructional materials agencies. The purpose of disseminating these courses was to make curriculum materials developed by the military more accessible to vocational educators in the civilian setting.

The course materials were acquired, evaluated by project staff and practitioners in the field, and prepared for dissemination. Materials which were specific to the military were deleted, copyrighted materials were either omitted or approval for their use was obtained. These course packages contain curriculum resource materials which can be adapted to support vocational instruction and curriculum development.

The National Center Mission Statement

The National Center for Research in Vocational Education's mission is to increase the ability of diverse agencies, institutions, and organizations to solve educational problems relating to individual career planning, preparation, and progression. The National Center fulfills its mission by:

- Generating knowledge through research
- Developing educational programs and products
- Evaluating individual program needs and outcomes
- Installing educational programs and products
- Operating information systems and services
- Conducting leadership development and training programs

FOR FURTHER INFORMATION ABOUT
Military Curriculum Materials
WRITE OR CALL
Program Information Office
The National Center for Research in Vocational Education
The Ohio State University
1960 Kenny Road, Columbus, Ohio 43210
Telephone: 614/486-3655 or Toll Free 800/848-4815 within the continental U.S. (except Ohio)

THE NATIONAL CENTER
FOR RESEARCH IN VOCATIONAL EDUCATION
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Military Curriculum Materials for Vocational and Technical Education

Information and Field Services Division

The National Center for Research in Vocational Education

Military Curriculum Materials Dissemination Is . . .

an activity to increase the accessibility of military-developed curriculum materials to vocational and technical educators.

This project, funded by the U.S. Office of Education, includes the identification and acquisition of curriculum materials in print form from the Coast Guard, Air Force, Army, Marine Corps and Navy.

Access to military curriculum materials is provided through a "Joint Memorandum of Understanding" between the U.S. Office of Education and the Department of Defense.

The acquired materials are reviewed by staff and subject matter specialists, and courses deemed applicable to vocational and technical education are selected for dissemination.

The National Center for Research in Vocational Education is the U.S. Office of Education's designated representative to acquire the materials and conduct the project activities.

Project Staff:

Wesley E. Budke, Ph.D., Director
National Center Clearinghouse

Shirley A. Chase, Ph.D.
Project Director

What Materials Are Available?

One hundred twenty courses on microfiche (thirteen in paper form) and descriptions of each have been provided to the vocational Curriculum Coordination Centers and other instructional materials agencies for dissemination.

Course materials include programmed instruction, curriculum outlines, instructor guides, student workbooks and technical manuals.

The 120 courses represent the following sixteen vocational subject areas:

Agriculture
Aviation
Building & Construction Trades
Clerical Occupations
Communications
Drafting
Electronics
Engine Mechanics
Food Service
Health
Heating & Air Conditioning
Machine Shop
Management & Supervision
Meteorology & Navigation
Photography
Public Service

The number of courses and the subject areas represented will expand as additional materials with application to vocational and technical education are identified and selected for dissemination.

How Can These Materials Be Obtained?

Contact the Curriculum Coordination Center in your region for information on obtaining materials (e.g., availability and cost). They will respond to your request directly or refer you to an instructional materials agency closer to you.

CURRICULUM COORDINATION CENTERS

EAST CENTRAL
Rebecca S. Douglass
Director
100 North First Street
Springfield, IL 62777
217/782-0759

MIDWEST
Robert Patton
Director
1515 West Sixth Ave.
Stillwater, OK 74704
405/377-2000

NORTHEAST
Joseph F. Kelly, Ph.D.
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225 West State Street
Trenton, NJ 08625
609/292-6562

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Building 17
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Olympia, WA 98504
206/753-0879

SOUTHEAST
James F. Shill, Ph.D.
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601/325-2510

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1776 University Ave.
Honolulu, HI 96822
808/948-7834

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

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Developed by:

United States Air Force

Development and Review Dates

April 15, 1975

D.O.T. No.:

637.281

Occupational Area:

Heating and Air Conditioning

Target Audiences:

Grades 11-adult

Print Pages:

518

Cost:

Availability:

Military Curriculum Project, The Center for Vocational Education, 1960 Kenny Rd., Columbus, OH 43210

Contents:	Type of Materials:						Instructional Design:				Type of Instruction:		
	Lesson Plans:	Programmed Text:	Student Workbook:	Handouts:	Text Materials:	Audio-Visuals:	Performance Objectives:	Tests:	Review Exercises:	Additional Materials Required:	Group Instruction:	Individualized:	
			No. of pages										
Block I – *Refrigeration and Air Conditioning Systems*			80					★					
Electrical Principles, Circuits, Components and Trouble Analysis	●		●		●	★	●		●	★	●		
Thermodynamics, Principles of Refrigeration	●		●		●	★	●		●		●		
Block II – *Major Components, Domestic and Commercial Refrigeration Systems*			49					★					
Refrigeration and Air Conditioning Components	●		●		●	★	●		●		●		
Domestic and Commercial Refrigeration Systems	●		●		●	★	●		●	★	●		
Block III – *Air Conditioning Systems*			67					★					
Air Movement, Calculations, and Psychrometrics	●		●		●	★	●		●	★	●		
Direct Expansion Air Conditioning Systems	●		●		●	★	●		●	★	●		
Centrifugal Air Conditioning Systems	●		●		●	★	●		●	★	●		
Absorption Systems	●		●		●	★	●		●	★	●		

★ Materials are recommended but not provided.

THE CENTER FOR VOCATIONAL EDUCATION
THE OHIO STATE UNIVERSITY

Expires July 1, 1978

Course Description

Training in this course includes refrigeration theory, refrigeration and air conditioning systems operating principles; psychrometrics; water treatment; electrical circuitry and test equipment; and the operation, maintenance, and troubleshooting of refrigeration and air conditioning systems and controls. A prerequisite for this course is **Refrigeration and Air Conditioning Specialist I through IX**, courses 11-6, 11-7, and 11-8 in this catalog. This course consists of three blocks covering 192 hours of instruction.

Block I — *Refrigeration and Air Conditioning Systems* contains two lessons including 77 hours of instruction. A third lesson on the course orientation has been deleted because it discusses military procedures and forms. The lesson topics and respective hours follow:

Electrical Principles, Circuit Components and Trouble Analysis (39 hours)
Thermodynamics, Principles of Refrigeration (38 hours)

Block II — *Major Components, Domestic and Commercial Refrigeration Systems* contains two lessons covering 46 hours of instruction.

Refrigeration and Air Conditioning Components (16 hours)
Domestic and Commercial Refrigeration Systems (30 hours)

Block III — *Air Conditioning Systems* contains four lessons covering 69 hours of instruction.

Air Movement, Calculations, and Psychrometrics (16 hours)
Direct Expansion Air Conditioning Systems (16 hours)
Centrifugal Air Conditioning Systems (20 hours)
Absorption Systems (17 hours)

This course contains both teacher and student materials. Printed instructor materials include lesson plans and a plan of instruction detailing the teaching steps by unit of instruction, criterion objectives, the duration of the lesson, and support material and guidance needed. Student materials consists of study guides containing text information and workbooks containing objectives, assignments, and review exercises for each block of instruction. The materials can be implemented as is or adapted for individualized remedial or independent study.

(PDS Code CVN)

PLAN OF INSTRUCTION

(Technical Training)

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

AIR TRAINING COMMAND

SHEPPARD TECHNICAL TRAINING CENTER

15 March 1974 - Effective 3 July 1974 with Class 740703
Changed 15 April 1975 - Effective 14 July 1975 with Class 750714

11-9

LIST OF CURRENT PAGES

This POI consists of 27 current pages issued as follows:

Page No.	Issue
*Title	15 Apr 75
*A	15 Apr 75
i	Original
*ii thru vii	15 Apr 75
1 thru 15	Original
Annex (3 pages)	12 Feb 74

CHANGE NOTICE INSTRUCTIONS

POI 3AZR54550-2, 15 March 1974, is changed as follows, effective 14 July 1975 with class 750714:

1. Make pen-and-ink changes identified on pages ii thru vii.

2. Insert changed and new pages and remove pages replaced according to above listing.

3. The (*) in the above page listing indicates that the page is a replacement or addition by this Change Notice.

FOR THE COMMANDER

LEONARD A. HAMILTON, Col, USAF
Chief, Dept of Civil Engineering Tng

DISTRIBUTION: ATC/TTMS-1, AULD - 1, SGPM - 1, TCE - 50, TTOT - 1, TTOX - 1, TTOR - 1, TTE - 1, CCAF/AY - 2

DEPARTMENT OF THE AIR FORCE
USAF School of Applied Aerospace Sciences (ATC)
Sheppard Air Force Base, Texas 76311

PLAN OF INSTRUCTION 3AZR54550-2
(PDS Code CVN)
15 March 1974

FOREWORD

1. PURPOSE. This plan of instruction prescribes the qualitative requirements for Course Number 3AZR54550-2, Refrigeration and Air Conditioning Equipment, in terms of criterion objectives presented by units/modules of instruction, and shows duration, correlation with the training standard, support materials, and instructional guidance. It was developed under the provisions of ATCR 52-33, Instructional System Development, and ATCR 52-7, Plans of Instruction.

2. COURSE DESCRIPTION. The course trains selected Air Force operating and maintenance personnel who possess AFSC 54450/70 or 54550/70 and who are not graduates of Course 3ABR54530, Refrigeration and Air Conditioning Specialist. It includes refrigeration theory, refrigeration and air conditioning systems operating principles, psychrometrics, water treatment, electrical circuitry and test equipment, and the operation, maintenance, and troubleshooting of refrigeration and air conditioning systems and controls. In addition, related training is provided on troop information program and commander's calls/briefings, etc.

3. EQUIPMENT ALLOWANCE AND AUTHORIZATION. Training equipment required to conduct this course is listed in Equipment Authorization Inventory Data Number 3ABR545300000. Training equipment authorizations for this course are based on the following Tables of Allowance:

TA 404	Civil Engineering Refrigeration, Air Conditioning, Heating Shops, and Central Heating Plants (WRAMA)
TA 483	Civil Engineering Water, Sewage Disposal Treatment, Potable Water Analysis and Pest Control (WRAMA)
TA 504	Food Service (Nontactical) (WRAMA)

NOTE: Group size is shown in parentheses after equipment listed in column 3 of numbered pages of this POI.

4. MULTIPLE INSTRUCTOR REQUIREMENTS. Units of instruction which require more than one instructor per instructional group are identified in the multiple instructor annex to this POI.

5. REFERENCES. This plan of instruction is based on COURSE TRAINING STANDARD SH52-3AZR54550-2, 6 November 1973, and COURSE CHART 3AZR54550-2, 23 January 1974.

FOR THE COMMANDER

FRANKLYN C. SNYDER, Colonel, USAF
Chief, Operations Division

Supersedes Plan of Instruction 3AZR54550-2, 30 August 1972
OPR: Department of Civil Engineering Training
DISTRIBUTION: Listed on Page A

PLAN OF INSTRUCTION	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK TITLE Refrigeration and Air Conditioning Systems	

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
1. Course Orientation a. Welcome b. Role of air power in peace in warfare c. Importance of course to the Air Force d. Individual benefits including CCAF credit hours to be gained from this course e. Disposition of course graduates f. Overview of course g. Responsibilities of students h. School policies and regulations, including grading practices i. Safety precautions j. Safeguarding classified information k. Counseling and remedial instruction l. Proficiency advancement of qualified students	1 Day 1 (1)	Column 1 Reference: None CTS Reference: None Instructional Materials SG 3AZR54550-2-I-1, Course Orientation AFM 127-101, Industrial ~~Safety Accident Prevention Handbook~~ TSCHR 50-30, Student Orientation ~~and Motivational Procedures~~ Prerecorded Slide: ATS 75-32, Student Critique Program Training Methods Discussion (1 hr) Instructional Environment/Design Classroom (1 hr) Group/Lockstep Instructional Guidance Welcome students to the course and stress benefits to be derived. Present an overview of the course, discussing school policies and regulations. Accident prevention, safety and emergency exercises shall be stressed. Discuss the chain of command and point out recreational facilities on the base and local area.

PLAN OF INSTRUCTION NO. 3AZR54550-2	DATE 15 March 1974	BLOCK NO. I	PAGE NO. 1

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)	3 SUPPORT MATERIALS AND GUIDANCE
m. Honor graduate program		
n. Shelter exercises and procedures		
o. Student critique program		
p. Necessity of clearing in through Student In-processing at Base Personnel		
q. Attendance mandatory unless officially excused		
r. Energy conservation		
s. Care of training literature		
2. Electrical Principles, Circuits, Components, and Trouble Analysis	39 Days 1 thru 5	**Column 1 Reference** **CTS Reference** 2a 1a, 1b, 1c, 1d, 1d(1), 1d(2), 1d(3) 2b 1e(1), 1e(2), 1e(3) 2c 1f(1), 1f(2), 1f(3) 2d 1g(1), 1g(2), 1g(3) 2e 1h(1), 1h(2) 2f 1i(1), 1i(2), 1i(3) 2g 1j(1), 1j(2), 1j(3), 1j(4) 2h 1k(1), 1k(2), 1k(3)
a. Using an electrical trainer and workbook, construct an operative simple dc circuit consisting of power source, protective device, switch, lamp, and an ammeter. Analyze the current flow observing all applicable safety precautions.	Day 1 (5/2)	
b. Using an electrical trainer and multimeter, measure voltage and resistance of circuits to an accuracy of ± 5%, observing all applicable safety precautions.	Day 2 (3/1)	**Instructional Materials** SG 3AZR54550-2-I-2, Electrical Principles, Circuits, Components, and Trouble Analysis WB 3AZR54550-2-I-2-P1, Identify Electrical Units, Construct and Analyze Current Flow in a Circuit

PLAN OF INSTRUCTION NO. 3AZR54550-2	DATE 15 March 1974	BLOCK NO. I	PAGE NO. 2

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
c. Using the workbook and wiring trainer, construct an operative series and parallel circuit. Using the multimeter apply Ohms Law and circuit characteristics to find the unknown factors for each circuit observing all applicable safety precautions. d. Using the workbook, multimeter, and electrical trainer locate 100% of the opens, shorts, and mechanical malfunctions observing all applicable safety precautions. e. Using the workbook, identify the operating characteristics of ac circuits containing capacitance and inductive reactance. f. Using workbook schematic and wiring trainer connect 110, 220 volt single-phase and 220 volt three-phase components to a power supply observing all workbook requirements and applicable safety precautions. g. Using workbook schematics, identify major components and wire schematically three-phase and single-phase motors observing data plate requirements.	(3/1) Day 3 (2/1) (1/.5) (3/.5) Day 4 (6/2)	WB 3AZR54550-2-I-2-P2, Multimeter Reading and Circuit Construction WB 3AZR54550-2-I-2-P3, Circuit Analysis WB 3AZR54550-2-I-2-P4, Reading a Motor Data Plate, Motor Construction and Wiring WB 3AZR54550-2-I-2-P5, Troubleshooting ac Circuits Textbook; Modern Refrigeration and Air Conditioning Audio Visual Aids Transparencies: Electrical Circuits Training Film 4144, Basic Electricity Training Film 6081, Basic Electricity ~~Slide Record Sets~~ Training Equipment Trainer, Fundamental electric principles (12) Bench item, Galvanometer (12) Bench item, Dynamo, hand-operated (12) Trainer, Multimeter Reading (1) Trainer, Multimeter (12) Trainer, DC Troubleshooting (12) Trainer, Component wiring (12) Trainer, Electric Motor (12) Trainer, AC Troubleshooting (12) Training Methods Discussion/demonstration (15 hrs) Performance (13 hrs) Training films (1 hr) Outside assignment (10 hrs)

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
h. Using the workbook, multimeter, and ac troubleshooting trainer locate 100% of the malfunctions on the 120 volt, 60 cycle, single-phase trainer, 100% of the malfunctions on the 220 volt, 60 cycle, single-phase trainer, and 100% of the malfunctions on the 220 volt, 60 cycle, three-phase trainer observing all applicable safety precautions.	Day 5 (6/2)	Instructional Environment/Design Classroom (16 hrs) Laboratory (13 hrs) Study Hall (10 hrs) Group/Lockstep Instructional Guidance Discuss the principles of electricity covering voltage, current, and resistance and the different types of circuits. Discuss care of meters and various types of electrical test instruments and their principles of application. Troubleshooting of dc electrical circuits using meters and ohms law. Discuss troubleshooting procedures for locating opens, shorts, and mechanical malfunctions in electrical circuits. Stress the difference between ac and dc electricity. Discuss wiring of electrical components to power supplies and the types of transformers. Discuss types of electric motors used in refrigeration and air conditioning, the major components and internal and external wiring. Discuss capacitors as to their types, selection and troubleshooting. Discuss procedures for troubleshooting ac circuits for opens, shorts and low power conditions. Use films and transparencies to aid the discussion and stress electrical safety at all times.
3. Thermodynamics, Principles of Refrigeration	38 Days 6 thru 10	Column 1 Reference — CTS Reference 3a — 2a, 2b, 2c, 2d, 2e 3b — 2f 3c — 2g, 2h, 2h(1) 3d — 2h(2)
a. Using a schematic of a refrigeration system name the components and trace the flow of refrigerant through the system.	Day 6 (6/2)	

PLAN OF INSTRUCTION (Continued)

1. UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)	3 SUPPORT MATERIALS AND GUIDANCE
b. Using selection charts and data provided, calculate the heat load for a given temperature and select and evaporator and condensing unit to handle this load for economical operation.	Day 7 (6/2)	**Instructional Materials** SG 3AZR54550-2-I-3, Thermodynamics, Principles of Refrigeration WB 3AZR54550-2-I-3-P1, Major Components and Refrigerant Flow Through a System WB 3AZR54550-2-I-3-P2, Calculating Heat Loads and Equipment Selection
c. Using a pressure-enthalpy diagram plot the refrigeration cycle.	Day 8 (6/2)	WB 3AZR54550-2-I-3-P3, Plotting the Refrigeration Cycle With the Pressure-Enthalpy Diagram WB 3AZR54550-2-I-3-P4, Plot the Refrigeration Cycle and Check Operation and Efficiency of a System Using the P. E. Diagram Textbook; Modern Refrigeration and Air Conditioning
d. Using the pressure-enthalpy diagram and the operating pressures of a refrigeration system, plot the cycle and operation of the system efficiency to a ± 5% of the rated system capacity.	Days 9, 10 (12/2)	**Audio Visual Aids** Transparencies Principles of Refrigeration ~~Slide Record Sets~~ Pressurated Sealing Refrigeration Cyc Charts Principles of Refrigeration Training Film 5536a, Basic Refrigeration **Training Methods** Discussion/Demonstration (18 hrs) Performance (11.5 hrs) Training Film (0.5 hr) Outside Assignment (8 hrs) **Instructional Environment/Design** Classroom (30 hrs) Study Hall (8 hrs) Group/Lockstep **Instructional Guidance** Discuss matter, pointing out its different states. Discuss heat, the types and methods of transfer. Use transparencies and training film 5536a to aid in discussing the refrigeration cycle.

PLAN OF INSTRUCTION NO.	DATE	BLOCK NO.	PAGE NO.
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PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
		Discuss methods of calculating heat loads and types of heat to be considered. Discuss the charts used to select equipment to remove the heat load calculated. Discuss checking system operation and efficiency using the P. E. diagram and different refrigerants. Discuss refrigerants and their thermodynamic properties and the P. E. chart and methods of plotting the cycle.
4. Related training (identified in Course Chart)	(2)	

PLAN OF INSTRUCTION	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK TITLE Major Components, Domestic and Commercial Refrigeration Systems	

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
1. Refrigeration and Air Conditioning Components	16 Days 11, 12	**Column 1 Reference** 1a — **CTS Reference** 3a(1), 3a(2), 3a(3), 3a(4), 3b(1), 3b(2), 3b(3), 3b(4), 3b(5), 3c(1), 3c(2), 3d(1), 3d(2), 3e(1), 3e(2), 3e(3), 3e(4), 3e(5), 3e(6), 3e(7), 3e(8), 3e(9), 3e(10), 3e(11), 3e(12)
a. Using workbook schematic, pressure and temperature readings, check the operation of the compressor, condenser, evaporator and metering device to provide correct operating conditions as specified by workbook requirements.	Day 11 (9/3)	1b — 3f
b. Using workbook schematic, selection charts, and data provided, size system liquid line, suction line, discharge line, and condenser to receiver drain line to provide acceptable pressure drop and gas velocity as specified by workbook requirements.	Day 12 (3/1)	**Instructional Materials** SG 3AZR54550-2-II-1, Major Components, Domestic and Commercial Refrigeration Systems WB 3AZR54550-2-II-1-P1, Check Operation of Compressor, Condenser, Evaporator and Metering Device, and Size Refrigeration System Piping Textbook; Modern Refrigeration and Air Conditioning **Audio Visual Aids** Transparencies - Refrigeration and Air Conditioning Components ~~Slide Record Sets~~ See pg 18 **Training Methods** Discussion/Demonstration (3 hrs) Performance (6 hrs) Training Films/Slides (3 hrs) Outside Assignments (4 hrs) **Instructional Environment/Design** Classroom (12 hrs) Study Hall (4 hrs) Group/Lockstep

PLAN OF INSTRUCTION NO.	DATE	BLOCK NO.	PAGE NO.
3AZR54550-2	15 March 1974	II	7

PLAN OF INSTRUCTION (Continued)

1 UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)
2. Domestic and Commercial Refrigeration Systems	30 Days 13, 14, 15, 16
a. Using a domestic refrigerator wiring diagram, schematically wire current flow thru hot wire, thermal, current, and potential relays for correct operation and schematically wire two and three terminal thermal overload protectors for correct operation.	Day 13 (6/2)
b. Using a hermetic compressor and multimeter, determine the common, start, and run terminals of the compressor and check the compressor for open or shorted motor windings.	Day 14 (3/1)
c. Using a hermetic compressor and motor starting cord and motor start analyzer check the compressor for operable condition.	(3/1)
d. Using a commercial refrigerating unit wiring diagram, schematically wire a magnetic line starter with line, load, and control circuits for correct operation.	Day 15 (2/.5)

3 SUPPORT MATERIALS AND GUIDANCE

Instructional Guidance

Discuss the major components of refrigeration systems using slide record sets and transparencies. Discuss refrigerant piping using slide record sets and transparencies.

Column 1 Reference	CTS Reference
2a	4a, 4b, 4c, 4c(1), 4c(2), 4c(3), 4c(4), 4c(5), 4d
2b	4e(1), 4e(2)
2c	4e(3), 4e(4)
2d	5a, 5b, 5c, 5c(1)
2e	5c(2)
2f	5c(3)
2g	5c(4)
2h	5d, 5d(1), 5d(2), 5d(3), 5d(4)

Instructional Materials

SG 3AZR54550-2-II-1, Major Components, Domestic and Commercial Refrigeration Systems
WB 3AZR54550-2-II-2-P1, Wiring Electrical Relays
WB 3AZR54550-2-II-2-P2, Analyzing Hermetic Compressors
WB 3AZR54550-2-II-2-P3, Wiring Commercial Systems
WB 3AZR54550-2-II-2-P4, Operation and Adjustment of Multi-evaporator Systems
Textbook; Modern Refrigeration and Air Conditioning

Audio Visual Aids

Transparencies - Domestic and Commercial Refrigeration Syste
Training Film, 6038a, Electrical Troubleshooting, Compressors
Training Film, 5624, Starting Relays
Training Film, 6038b, Electrical Troubleshooting, Compressors
Training Film, TF6038b, Compressors, Hermetic and Semihermetic - Starting Relay Circuits
Prenarrated Slides. Basic Cycle Controls
Prenarrated Slides. ATS 54-8 Cleanout after Burn

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
e. Using a commercial refrigerating unit wiring diagram, schematically wire temperature low and high pressure motor controls and compute adjustments to maintain desired conditions stated in the workbook.	(2/.5)	Training Equipment Trainer, Hermetic Compressor (12) Trainer, Multiple Evaporator System (12) Multimeter (12) Motor Starting Cord (12) Motor Start Analyzer (12)
f. Using a commercial refrigerating unit wiring diagram, schematically wire an oil pressure safety failure control and compute adjustment to maintain the conditions specified in the workbook.	(1/.5)	Training Methods Discussion/Demonstration (9 hrs) Performance (12 hrs) Training Film (3 hrs) Outside Assignment (6 hrs)
g. Using a commercial refrigerating unit wiring diagram, schematically wire an automatic defrost control and compute adjustment to maintain condition specified in the workbook.	(1/.5)	Instructional Environment/Design Classroom (18 hrs) Laboratory (6 hrs) Study Hall (6 hrs) Group/Lockstep
h. Operate and adjust a multi-evaporator system to maintain the different spaces to the temperatures specified in the workbook.	Day 16 (6/0)	Instructional Guidance Discuss domestic refrigeration and the construction features of domestic refrigerators. Use transparencies and training films to aid in the discussion of wiring and relays. Discuss the construction and types of hermetic compressors used in domestic refrigeration. Use training film to aid in the discussion of methods of analyzing hermetic compressors. Stress safety practices involved. Discuss the construction and major components of a typical walk-in system. Use transparencies and training film to aid in the discussion of wiring and adjustment of control systems common to commercial systems. Discuss the purpose of multiple systems and the methods used to obtain different areas at different temperatures. Use transparencies to aid in the discussion to illustrate the use of control devices and their adjustment. Emphasize safety at all times.
3. Related Training (identified in Course Chart)	(2)	

PLAN OF INSTRUCTION	COURSE TITLE Refrigeration and Air Conditioning Equipment

BLOCK TITLE
Air Conditioning Systems

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2
1. Air Movement, Calculations, and Psychrometrics	16 Days 17, 18
a. Using sling psychrometer, determine the wet bulb and dry bulb temperatures of air, and wet bulb depression, within 2% accuracy.	Day 17 (1/.5)
b. Using workbook and psychrometeric chart, plot given air measurements to determine the air conditions to within 2% accuracy.	(2/.5)
c. Using workbook project, handout reference tables, and load estimate forms, estimate the sensible, latent, total hourly heat load, and sensible heat ratio of the load to 95% accuracy.	(3/1)
d. Using psychrometric chart and workbook exercises, determine air mixture for final conditions and solve air conditioning processes problems to within 2% accuracy.	Day 18 (2/.5)
e. Using psychrometric chart and heat load estimate results, determine within 5% accuracy, the supply air condition and volume requirements to remove the hourly sensible and latent heat loads to maintain comfort conditions within a given building.	(2/1)

SUPPORT MATERIALS AND GUIDANCE 3

Column 1 Reference	CTS Reference
1a	6a, 6b, 6b(1), 6b(2)
1b	6a, 6b, 6b(1), 6b(2)
1c	6a, 6b, 6b(1), 6b(2)
1d	6b(3), 6b(4), 6b(5)
1e	6b(3), 6b(4), 6b(5)
1f	6b(3), 6b(4), 6b(5)

Instructional Materials
SG 3AZR54550-2-III-1, Air Movements, Calculations, and Psychrometrics
WB 3AZR54550-2-III-1-P1, Determining Wet Bulb, Dry Bulb and Wet Bulb Depression
WB 3AZR54550-2-III-1-P2, Air Conditioning Process Calculations
Textbook: Carrier Air Distribution Manual

Audio Visual Aids
Transparencies - Air Movement and Psychrometrics
~~Slide Record Sets~~ Presentation Slides ATS 54-11, 12, 13 Psychrometrics
Charts - Air Movement and Psychrometrics

Training Equipment
Chart, Psychrometric (12)
Sling Psychrometer (1)
Ductulator (12)

Training Methods
Discussion/Demonstration (4 hrs)
Performance (8 hrs)
Outside Assignment (4 hrs)

PLAN OF INSTRUCTION NO. 3AZR54550-2	DATE 15 March 1974	BLOCK NO. III	PAGE NO. 10

PLAN OF INSTRUCTION (Continued)

1 UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)	3 SUPPORT MATERIALS AND GUIDANCE
f. Using calculated air volumes and workbook steps, adjust air volumes to within 5% of the specified CFM for each outlet of an air distribution system.	(2/.5)	Instructional Environment/Design Classroom (12 hrs) Study Hall (4 hrs) Group/Lockstep Instructional Guidance Discuss the terms relating to the psychrometric chart and the procedures for determining the properties and conditions of air. Discuss the procedures for determining and calculating air conditioning heat loads. Discuss air mixing methods and how to determine the final condition. Discuss the different types of air measuring instruments and their uses. The classification and sizing of ducts and methods of determining CFM requirements shall be discussed using the ductulator and selection tables.
2. Direct Expansion Air Conditioning Systems	16 Days 19, 20	Column 1 Reference — CTS Reference 2a — 7a, 7b, 7c 2b — 7d, 7d(1), 7d(2), 7d(3), 7d(4), 7d(5), 7d(6) Instructional Materials SG 3AZR54550-2-III-2, Direct Expansion Air Conditioning Systems WB 3AZR54550-2-III-2-P1, Operate and Service Window Air Conditioning WB 3AZR54550-2-III-2-P2, Operate and Electrically Troubleshoot Residential Air Conditioning Textbook: Modern Refrigeration and Air Conditioning Audio Visual Aids Transparencies Direct Expansion Air Conditioning Systems ~~Slide Record Sets~~ Training Film, 6361, Home Heating and Air Conditioning Control Systems Charts - Direct Expansion Air Conditioning Systems Training Equipment Trainer, Air Conditioner, Residential (12) Trainer, Air Conditioner, Window (12)
a. Using assigned window air conditioning unit and workbook project, operate and service the unit to specifications listed in the workbook.	Day 19 (6/2)	
b. Given a wiring diagram of the control and power circuits of a residential air conditioning unit and a list of trouble symptoms, determine the cause of each listed trouble.	Day 20 (6/2)	

PLAN OF INSTRUCTION (Continued)

1 UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)	3 SUPPORT MATERIALS AND GUIDANCE
		Training Methods Discussion/Demonstration (4 hrs) Performance (7.5 hrs) Training Film (0.5 hr) Outside Assignment (4 hrs) Instructional Environment/Design Classroom (4.5 hrs) Laboratory (7.5 hrs) Study Hall (4 hrs) Group/Lockstep Instructional Guidance Discuss air conditioning fundamentals covering the definition and types. Discuss window air conditioning units stressing the operation, service, and troubleshooting. Emphasize safety as applicable. Discuss the residential unit covering components and their functions, use transparencies and training film to discuss unit wiring and control systems. Stress troubleshooting electrical systems and residential unit service procedures.
3. Centrifugal Air Conditioning Systems	20 Days 21, 22, and 23	Column 1 Reference — CTS Reference 3a — 7e, 7e(1), 7e(2), 7e(3), 7e(4) 3b — 7e(5) 3c — 7e(6)
a. Using a centrifugal system schematic, plot the flow of refrigerant through the system and label the plots to identify the components and state of refrigerant to conditions specified by the workbook.	Day 21 (6/2)	Instructional Materials SG 3AZR54550-2-III-3, Centrifugal Air Conditioning Systems WB 3AZR54550-2-III-3-P1, Centrifugal Refrigeration Components and Cycle WB 3AZR54550-2-III-3-P2, Centrifugal Refrigeration Capacity Control WB 3AZR54550-2-III-3-P3, Troubleshooting Centrifugal Systems Manual: Carrier Centrifugal Air Conditioning Equipment

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
b. Using workbook and equipment provided, locate, identify, and give the function and operation of the capacity controls of centrifugal systems. c. Using given centrifugal refrigeration machine problems and troubleshooting chart, identify probable causes and list remedies for system failures.	Day 22 (6/2) Day 23 (3/1)	Audio Visual Aids Transparencies Centrifugal Air Conditioning Systems ~~Slide Record Sets~~ Prenarrated Slides. Centrifugal Equipment ~~Charts~~ Prenarrated Slides: Dehydration Training Equipment Trainer, Air Conditioning, 100 Ton Centrifugal (12) Training Methods Discussion/Demonstration (9 hrs) Performance (6 hrs) Outside Assignment (5 hrs) Instructional Environment/Design Classroom/Field Trip (13 hrs) Laboratory (2 hrs) Study Hall (5 hrs) Group/Lockstep Instructional Guidance Discuss the relationship between reciprocating and centrifugal systems. When plotting the refrigeration cycle discuss the states of the refrigerant and the major components of the system. During the discussion use transparencies and slides to aid in student understanding. Discuss the methods and types of capacity control systems used in centrifugal refrigeration systems. Take students on a field trip to various buildings to view equipment of different manufacturers. During the tour emphasize control locations and similarity of operation. Discuss the possible troubles that may occur with centrifugal machines, their symptoms, and the remedy for each trouble.

PLAN OF INSTRUCTION (Continued)

UNITS OF INSTRUCTION AND CRITERION OBJECTIVES 1	DURATION (HOURS) 2	SUPPORT MATERIALS AND GUIDANCE 3
		Instructional Environment/Design Classroom (8 hrs) Laboratory (4 hrs) Field Trip (2 hrs) Study Hall (3 hrs) Group/Lockstep Instructional Guidance Discuss the principle of operation, location of components, and the flow of system fluids through the lithium bromide system. Use transparencies and training film to aid in the discussion. Discuss the methods of servicing and checking absorption machine performance using charts and graphs. Take students on a field trip to 1000 man dormitory to view machines pointing out service points and system components. Using transparencies and charts discuss the control sequence of operation for a typical lithium bromide machine. Discuss pneumatic control terms and demonstrate calibration of a capacity controller. Discuss the possible troubles that may occur, their symptoms, and the remedy for each trouble. Conduct course critique.
5. Related Training (identified in course chart)	2	
6. Course Critique and Graduation	(1.0)	

PLAN OF INSTRUCTION (Continued)

1 UNITS OF INSTRUCTION AND CRITERION OBJECTIVES	2 DURATION (HOURS)	3 SUPPORT MATERIALS AND GUIDANCE
4. Absorption Systems	17 Days 23, 24 and 25	**Column 1 Reference** / **CTS Reference** 4a — 7f, 7f(1), 7f(2), 7f(3) 4b — 7f(4) 4c — 7f(5) 4d — 7f(6) 4e — 7f(7) **Instructional Materials** SG 3AZR54550-2-III-4, Absorption Systems WB 3AZR54550-2-III-4-P1, Absorption Refrigeration Components and Cycle WB 3AZR54550-2-III-4-P2, Servicing Absorption Systems WB 3AZR54550-2-III-4-P3, Absorption Electrical Systems WB 3AZR54550-2-III-4-P4, Absorption System Capacity Controls WB 3AZR54550-2-III-4-P5, Troubleshooting Absorption Systems Manual: York Operation, Service and Maintenance **Audio Visual Aids** Transparencies ~~Slide Record Sets~~ Absorption Systems Training Film CE-9, Lithium Bromide Air Conditioning ~~Charts~~ Prenarrated Slides: Absorption Systems **Training Equipment** Trainer, Refrigeration Controls (12) **Training Methods** Discussion/Demonstration (9.5 hrs) Performance (4 hrs) Film (0.5 hr) Outside Assignment (3 hrs) Graduation (1 hr)
a. Using an absorption system schematic, identify major components and trace system fluids flow to conditions specified in the workbook.	Day 23 (3/1)	
b. Using workbook project, determine the condition of machine vacuum and list the procedures for charging or removing refrigerant and absorbent maintaining a solution concentration as specified by the workbook.	Day 24 (6/2)	
c. Using an absorption unit wiring diagram, trace the sequence of operation for startup and shutdown of a lithium bromide machine.	Day 25 (2/0)	
d. Using assigned trainer, calibrate and adjust a capacity controller to maintain 70°F ± 2°F.	(2/0)	
e. Given a lithium bromide troubleshooting chart, complete workbook project by stating troubleshooting procedures on a system.	(1/0)	

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE	INSTRUCTOR
COURSE NUMBER 3A[illegible]550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER I	BLOCK TITLE Refrigeration and Air Conditioning Systems

LESSON TITLE
Electrical Principles, Circuits, Components and Trouble Analysis (Days 1 thru 5)

LESSON DURATION

CLASSROOM/Laboratory	Complementary	TOTAL
29 Hrs	10 Hrs	39 Hrs

POI REFERENCE

PAGE NUMBER	PAGE DATE	PARAGRAPH
2 thru 4	15 March 1974	2a, b, c, d, e, f, g, h.

STS/CTS REFERENCE

NUMBER	DATE
CTS SH52-3AZR54550-2	6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Trainer, Fund. Elect. Principles Bench item, Galvanometer Bench item, Dynamo Trainer, Multimeter Reading Trainer, Multimeter Trainer, d.c. Trouble shooting Trainer, Component Wiring Trainer, Electric Motor Trainer, a.c. Trouble shooting	NONE	NONE	Transparencies, [illegible] Training Film 4144 Training Film 6081 ~~[illegible]~~ SG-I-2 WB-I-2-P1 thru P5 Textbook; Modern Refrigeration and Air Conditioning ~~[illegible]~~

CRITERION OBJECTIVES AND TEACHING STEPS

2a. Using an electrical trainer and workbook, construct an operative simple d.c. circuit consisting of power source, protective device, switch, lamp, and an ammeter. Analyze the current flow observing all applicable safety precautions

(1) definition of electricity

(2) sources of electrical energy

(3) definition of voltage, its effects and related factors

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

(4) definition of current, its effects and related factors

(5) definition of resistance, its effects and related factors

(6) conductors, insulators and their requirements

(7) requirements of a simple circuit

(8) requirements of a series circuit

(9) requirements of a parallel circuit

2b. Using a electrical trainer and multimeter, measure voltage and resistance of circuits to an accuracy of ± 5%, observing all applicable safety precautions.

(1) purpose and operational applications of the voltmeter, ammeter, and ohmmeter

(2) safety precautions as applied to multimeters

2c. Using the workbook and wiring trainer, construct an operative series and parallel circuit. Using the multimeter apply Ohms Law and circuit characteristics to find the unknown factors for each circuit observing all applicable safety precautions

(1) Ohms Law and operating characteristics of a simple circuit

(2) Ohms Law and operating characteristics of a series circuit

(3) Ohms Law and operating characteristics of a parallel circuit

2d. Using the workbook, multimeter, and electrical trainer, locate 100% of the opens, shorts, and mechanical malfunctions observing all applicable safety precautions

(1) troubleshooting a circuit to locate opens

(2) troubleshooting a circuit to locate shorts

(3) troubleshooting a circuit for low power and mechanical malfunctions

2e. Using the workbook, identify the operating characteristics of a.c. circuits containing capacitance and inductive reactance

(1) difference between a.c. and d.c. electricity

(2) frequency

(3) cycle

(4) alternation

(5) sine wave

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

(6) generation

(7) coil in an a.c. circuit

(8) capacitor in an a.c. circuit

2f. Using workbook schematic and wiring trainer connect 110, 220 volts single-phase and 220 volt three-phase components to a power supply observing all [illegible] requirements and applicable safety precautions

(1) single-phase transformers

(2) Wye-type three-phase transformers

(3) Delta-type three-phase transformers

(4) circuit wiring requirements

2g. Using workbook schematics, identify major components and wire schematically three-phase and single-phase motors observing data plate requirements

(1) Major components of three-phase motors

(2) principles of operation of three-phase motors

(3) internal and external wiring of three-phase motors

(4) major components of single-phase motors

(5) principles of operation of single-phase motors

(6) internal and external wiring of single-phase motors

(7) types, selection and troubleshooting capacitors

2h. Using the workbook, multimeter, and a.c. troubleshooting trainer locate 100% of the malfunctions on the 120 volt, 60 cycle, single-phase trainer, 100% of the malfunctions on the 220 volt, 60 cycle, single-phase trainer, and 100% of the malfunctions on the 220 volt, 60 cycle, three-phase trainer observing all applicable safety precautions

(1) troubleshooting procedures for opens in an a.c. circuit

(2) troubleshooting procedures for shorts in an a.c. circuit

(3) troubleshooting procedures for low power in an a.c. circuit

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE [illegible] 8 JUN 1974	INSTRUCTOR
COURSE NUMBER 3AZ[illegible]4550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER I	BLOCK TITLE Refrigeration and Air Conditioning Systems

LESSON TITLE Thermodynamics, Principles of Refrigeration (Days 6 thru 10)

LESSON DURATION

CLASSROOM/Laboratory 28.5-30 Hrs	Complementary 8 Hrs	TOTAL 36.5-38 Hrs

POI REFERENCE

PAGE NUMBER 4 and 5	PAGE DATE 15 March 1974	PARAGRAPH 3a, b, c, d.

STS/CTS REFERENCE

NUMBER CTS 3E52-3AZR54550-2	DATE 6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
NONE	NONE	NONE	~~[illegible]~~, Forward Training Film 5536 A ~~Slide-Record-sets~~ Charts, ~~SC-I-3~~ WP-I-3- P1 thru P4, Textbook: Modern Refrigeration and Air Conditioning [illegible]

CRITERION OBJECTIVES AND TEACHING STEPS

3a. Using a schematic of a refrigeration system, name the components and trace the flow of refrigerant thru the system.

~~[illegible]~~
Refrigeration Cycle, ~~[illegible]~~
~~[illegible] characteristics, Charging and Discharging the System~~

(1) matter

(2) heat

(3) temperature

(4) heat flow and transfer

(5) pressure and density

(6) gas laws

(7) refrigeration cycle

3b. Using selection charts and data provided, calculate the heat load for a given temperature and select an evaporator and condensing unit to handle this load for economical operation

(1) heat load estimation

(2) sensible heat

(3) radiation heat

(4) solar heat

(5) latent heat

(6) air changes

(7) product heat

(8) miscellanious heat

(9) short form estimations (charts)

3c. Using a pressure-enthalpy diagram plot the refrigeration cycle

(1) refrigerants

(2) requirements of refrigerants

(3) physical properties of refrigerants

(4) classification of refrigerants

(5) pressure-enthalpy diagram

(6) regions of the pressure-enthalpy diagram

(7) scales and lines of the pressure-enthalpy diagram

(8) plotting the refrigeration cycle

3d. Using the pressure-enthalpy diagram and the operating pressures of a refrigeration system, plot the cycle and operation of the system efficiency to a ± 5% of the rated system capacity

(1) vapor-compression cycle analysis with the P.E. diagram

(2) refrigeration effect

(3) refrigerant loss

(4) superheat

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

(5) heat of compression

(6) subcooling

(7) compression ratio

(8) refrigerant circulated

(9) compression work

(10) co-efficient of performance

(11) compressor hoursepower per ton

(12) system analysis using refrigerant 12 and 22 P.E. charts

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TTS /[illegible]	INSTRUCTOR
COURSE NUMBER 3ABR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER II	BLOCK TITLE Major Components, Domestic and Commercial Refrigeration Systems.

LESSON TITLE
Refrigeration and Air Conditioning Components (Days 11 thru 12)

LESSON DURATION

CLASSROOM/Laboratory	Complementary	TOTAL
12 Hrs	4 Hrs	16 Hrs

POI REFERENCE

PAGE NUMBER	PAGE DATE	PARAGRAPH
7	15 March 1974	1a, b.

STS/CTS REFERENCE

NUMBER	DATE
CTS SH52-3AZR54550-2	6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
NONE	NONE	NONE	Transparencies, Delete ~~Slide-Record Sets~~ SG-II-1 WB-II-1-P1 Textbook; Modern Refrigeration and Air Conditioning Recommended Delete!

CRITERION OBJECTIVES AND TEACHING STEPS

1a. Using workbook schematic, pressure and temperature readings, check the operation of the compressor, condenser, evaporator, and metering device to provide correct operating conditions as specified by workbook requirements.

(1) refrigeration and Air Conditioning Components

(2) Compressors

(3) Condensers

(4) Evaporators

(5) Metering Devices

(6) Accessories

ATS 54-1 ~~[illegible]~~, [illegible], ATS-3 Metering Devices, ATS 54-5 Accessories, ATS 54-2 ~~[illegible]~~ Condensers And Receivers ~~[illegible]~~ Evaporators

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1b. Using workbook schematic, selection charts, and data provided, size system liquid line, suction line, discharge line, and condenser to receiver drain line to provide accpptable pressure drop and gas velocity as specified by workbook requirements.

(1) Liquid Line

(2) Suction Line

(3) Discharge Line

(4) Condenser Drain Line

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TCETC /28 Mar 74	INSTRUCTOR
COURSE NUMBER 3AZR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER II	BLOCK TITLE Major Components, Domestic and Commercial Refrigeration Systems

LESSON TITLE
Domestic and Commercial Refrigeration Systems (Days 13 thru 16)

LESSON DURATION

CLASSROOM/Laboratory 22.5 ~~24~~ Hrs	Complementary 6 Hrs	TOTAL 28.5 ~~30~~ Hrs

POI REFERENCE

PAGE NUMBER ~~8 and 9~~	PAGE DATE 15 March 1974	PARAGRAPH 2a, b, c, d, e, f, g, h.

STS/CTS REFERENCE

NUMBER CTS-SH52-3AZR54550-2	DATE 6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Trainer, hermetic compressor. Multimeter Motor starting cord Motor start analyzer Trainer, multiple evaporator System	NONE	NONE	Transparencies, 19 Training Film 6038 A Training Film 5624 Training Film 6038 B SG-II-1 WB-II-2-P1 thru P4 Textbook: Modern Refrigeration and Air Conditioning

CRITERION OBJECTIVES AND TEACHING STEPS

2a. Using a domestic refrigerator wiring diagram, schematically wire current flow thru hot wire, thermal, current, and potential relays for correct operation and schematically wire two and three terminal thermal overload protectors for correct operation.

(1) domestic refrigeration

(2) construction

(3) refrigeration components

(4) electrical circuits

Premounted slides: Compressor [illegible] [illegible], [illegible]
AIS 54-3 Cleanout after Burnout, ~~AIS 54-7~~
~~Troubleshooting~~

GPO: 1973 779-384/21

2b. Using a hermetic compressor and multimeter, determine the common, start, and run terminals of the compressor and check the compressor for open or shorted motor windings.

(1) method for determining hermetic motor terminals

(2) method for checking hermetic compressor motor windings

2c. Using hermetic compressor and motor starting cord and motor start analyzer check the compressor for operable condition.

(1) method for checking a hermetic compressor with a starting cord

(2) method for checking a hermetic compressor with a motor start analyzer

2d. Using a commercial refrigerating unit wiring diagram, schematically wire a magnetic line starter with line, load, and control circuit for correct operation.

(1) commercial systems (walk-ins)

(2) refrigeration components

(3) electrical circuits

2e. Using a commercial refrigerating unit wiring diagram, schematically wire temperature , low and high pressure motor controls and compute adjustments to maintain desired conditions stated in the workbook.

(1) temperature controls

(2) low pressure motor control

(3) high pressure motor control

2f. Using a commercial refrigerating unit wiring diagram, schematically wire an oil pressure safety failure control and compute adjustment to maintain the condition specified in the workbook.

(1) control operating pressures

(2) operation/wiring

(3) adjustment

(4) checking OPSS

2g. Using a commercial refrigerating unit wiring diagram, schematically wire an automatic defrost control and compute adjustment to maintain conditions specified in the workbook.

(1) types of defrost systems

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(2) defrost control operation/ wiring

(3) adjustment

(4) checking defrost controls

2h. Operate and adjust a multi-evaporator system to maintain the different spaces to the temperatures specified in the workbook.

(1) purpose and application of multi-evaporator systems

(2) single temperature multi-evaporator systems

(3) multiple temperature multi-evaporator systems

(4) operation and adjustment of multi-evaporator systems

(5) multiple compressor systems

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TCHTC/ [illegible]	INSTRUCTOR
COURSE NUMBER 3AZR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER III	BLOCK TITLE Air Conditioning Systems

LESSON TITLE
Air Movement, Calculations, and Psychrometrics (Days 17 and 18)

LESSON DURATION

CLASSROOM/Laboratory	Complementary	TOTAL
12 Hrs	4 Hrs	16 Hrs

POI REFERENCE

PAGE NUMBER	PAGE DATE	PARAGRAPH
10 and 11	15 March 1974	1a, b, c, d, e, f.

STS/CTS REFERENCE

NUMBER	DATE
CTS SH52-3AZR54550-2	6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Chart, Psychrometric Sling Psychrometer Ductulator	NONE	NONE	Transparencies, Air [illegible] ~~[illegible] Record Sets~~ Charts SG-III-1 WB-III-1-P1 thru 12 Textbook: Carrier Air Distribution Manual ~~Commercial Slides~~

CRITERION OBJECTIVES AND TEACHING STEPS

1a. Using sling psychrometer, determine the wet bulb and dry bulb temperatures of air, and wet bulb depression, with-in 2% accuracy.

PTS 54-11, 12 & 13 [illegible]
Psychrometrics, PTS 54-6-The [illegible]
~~[illegible] Heat Pump~~

(1) basic psychrometer

(2) psychrometer use and readings

(3) purpose and significance of psychrometer readings

1b. Using workbook and psychrometric chart, plot given air measurements to determine the air conditiond to within 2% accuracy.

(1) lines and scales of the psychrometric chart

(2) interpreting the condition of the air.

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

1c. Using workbook project, handout reference tables and load estimate forms, estimate the sensible, latent, total hourly heat load, and sensible heat ratio of the load to a 95% accuracy

(1) purpose

(2) sources of heat

(3) heat flow terminology

(4) how heat enters the conditioned space

(5) heat flow and insulation ratings

(6) basic heat flow formula and application

(7) load estimating considerations and procedures

1d. Using psychrometric chart and workbook exercises, determine air mixtures for final conditions and solve air conditioning process problems to within 2% accuracy

(1) air conditioning processes on the chart

(2) simple air conditioning process problems

(3) determine condition of air being mixed and the resultant mixture

1e. Using psychrometric chart and heat load estimate results, determine within 5% accuracy, the supply air condition and volume requirements to remove the hourly sensible and latent heat loads to maintain comfort conditions within a given building

(1) determine SHF.

(2) plotting SHF reference line and cooling process

(3) determine supply air volume

(4) determine correct duct size

(5) air side capacity check

1f. Using calculated air volumes and workbook steps, adjust air volumes to within 5% of the specified CFM for each outlet of an air distribution system

(1) purpose

(2) requirements

(3) procedures

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TCSTC/23J--	INSTRUCTOR
COURSE NUMBER 3AZR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER III	BLOCK TITLE Air Conditioning Systems

LESSON TITLE
Direct Expansion Air Conditioning Systems (Days 19 and 20)

LESSON DURATION

CLASSROOM/Laboratory	Complementary	TOTAL
12 Hrs	4 Hrs	16 Hrs

POI REFERENCE

PAGE NUMBER	PAGE DATE	PARAGRAPH
11	15 March 1974	2a, b.

STS CTS REFERENCE

NUMBER	DATE
CTS 3H52-3AZR54550-2	6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY*	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Trainer, Window Unit Air Conditioner Trainer, Residential Air Conditioner	NONE	NONE	Transparencies, ~~[illegible]~~ Training Film 6361 SG-III-2 WB-III-2-P1 and P2 Charts Textbook: Modern Refrigeration and Air Conditioning

CRITERION OBJECTIVES AND TEACHING STEPS

2a. Using assigned window air conditioning unit and workbook project, operate and service the unit to specifications listed in the workbook

(1) types of air conditioning units

(2) operation and troubleshooting windoe air conditioners

(3) service procedures for window air conditioners

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CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

2b. Given a wiring diagram of the control and power circuits of a residential air conditioner and a list of trouble symptoms, determine the cause of each listed trouble

(1) air circulating system components

(2) furnace system components

(3) cooling system components

(4) electrical system

(5) control circuits

(6) service and maintenance of residential air conditioners

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TCMTG/	INSTRUCTOR
COURSE NUMBER 3AZR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER III	BLOCK TITLE Air Conditioning System

LESSON TITLE
Centrifugal Air Conditioning Systems (Days 21 thru 23)

LESSON DURATION

CLASSROOM/Laboratory	Complementary	TOTAL
15 Hrs	5 Hrs	20 Hrs

POI REFERENCE

PAGE NUMBER	PAGE DATE	PARAGRAPH
12 and 13	15 March 1974	3a, b, c.

STS/CTS REFERENCE

NUMBER	DATE
CTS SN52-3AZR54550-2	6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Trainer, 100 Ton Centrifugal Air Conditioner	NONE	NONE	Transparencies, Centrifugal Air Conditioning Systems ~~Tape-Record-Sets~~ ~~Charts~~ Manual: Carrier Centrifugal Refrigeration Equipment SG-III-3 WB-III-3-P1 thru P3

CRITERION OBJECTIVES AND TEACHING STEPS

3a. Using centrifugal system schematic, plot the flow of refrigerant through the system and label the plots to identify the components and state of refrigerant to conditions specified by the workbook.

(1) indirect expansion cooling

(2) centrifugal machine refrigerants

(3) basic centrifugal refrigeration cycles

(4) liquid refrigerant control methods

(5) major centrifugal machine components

(6) motor cooling methods

~~Carrier Presentation~~, Centrifugal Equipment
Prenarrated Slides: Dehydration

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

(7) compressor lubrication methods

(8) purge recovery methods

3b. Using workbook and equipment provided, locate, identify, and give the function and operation of the capacity controls of centrifugal systems.

(1) capacity control methods

3c. Using given centrifugal refrigeration machine problems and troubleshooting chart, identify probable causes and list remedies for system failures

(1) safety and power electrical circuits

(2) electronic control systems

(3) troubleshooting

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LESSON PLAN (Part I, General)

APPROVAL OFFICE AND DATE TGAIC / ...	INSTRUCTOR
COURSE NUMBER 3AZR54550-2	COURSE TITLE Refrigeration and Air Conditioning Equipment
BLOCK NUMBER III	BLOCK TITLE Air Conditioning Systems

LESSON TITLE
Absorption Systems (Days 23 thru 25)

LESSON DURATION

CLASSROOM/Laboratory 12.5 ~~24~~ Hrs	Complementary 3 Hrs	TOTAL 15.5 ~~27~~ Hrs

POI REFERENCE

PAGE NUMBER 14	PAGE DATE 15 March 1974	PARAGRAPH 4a, b, c, d, e.

STS/CTS REFERENCE

NUMBER CTS, SH52-3AZR54550-2	DATE 6 Nov. 73

SUPERVISOR APPROVAL

SIGNATURE	DATE	SIGNATURE	DATE

PRECLASS PREPARATION

EQUIPMENT LOCATED IN LABORATORY	EQUIPMENT FROM SUPPLY	CLASSIFIED MATERIAL	GRAPHIC AIDS AND UNCLASSIFIED MATERIAL
Trainer, refrigeration controls	NONE	NONE	Transparencies, ~~Slide Nos.~~ Charts SG-III-4 WB-III-4-P1 thru P5 Manual: York Operation Service and Maintenance.

CRITERION OBJECTIVES AND TEACHING STEPS

4. Absorption Systems
   4 a. Using an absorption system schematic, identify major components and trace system fluids flow to conditions specified by the workbook.

      (1) development of absorption cooling

      (2) applications

      (3) system components

      (4) system fluids

      (5) system characteristics

      (6) system fluids flow/cycle

~~Slide Presentation~~, Absorp. Systems.

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

4b. Using workbook project, determine the condition of machine vacuum and list procedures for charging or removing refrigerant and absorbent, maintaining a solution concentration as specified by the workbook.

(1) standing vacuum test

(2) running vacuum test

(3) leak testing

(4) charging refrigerant and/or absorbent

(5) removing refrigerant and/or absorbent

(6) solution concentration check

4c. Using an absorption unit wiring diagram, trace the sequence of operation for start-up and shut-down of a lithium bromide machine.

(1) types of control systems

(2) control operation/start-up

(3) control operation/shut-down

4d. Using assigned trainer, calibrate and adjust capacity controller to maintain 70 degrees F., ± 2 degrees F.

(1) pneumatic control terms

(2) LP914A sensor components/operation

(3) LP914A sensor operational checks

(4) RP908A controller components/operation

(5) RP908A chilled water controller calibration

4e. Given lithium bromide machine troubleshooting chart, complete workbook project by stating troubleshooting procedures on a system.

(1) solidification at start-up

(2) solidification during operation

(3) low capacity

(4) solidification at shut-down

(5) air leak into machine

LESSON PLAN (Part I General) CONTINUATION SHEET

CRITERION OBJECTIVES AND TEACHING STEPS (Continued)

(6) machine shut-down on safety controls

(7) loss of vacuum at shut-down

(8) failure to keep machine purged

PREPARE THE MAN

SG 3AZR54550-2-I-1 through 3

DEPARTMENT OF CIVIL ENGINEERING TRAINING

Refrigeration and Air -Conditioning Equipment

REFRIGERATION AND AIR-CONDITIONING SYSTEMS

28 June 1974

SHEPPARD AIR FORCE BASE

11-9

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42

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

BLOCK I

(Days 1--10)

Unit	Title	Page
I-1	Course Orientation	1
I-2	Electrical Principles, Circuits, Components, and Trouble Analysis	5
I-3	Thermodynamics, Principles of Refrigeration	65

IB 75-77

MODIFICATIONS

Unit I-1 of this publication has (have) been deleted in adapting this material for inclusion in the "Trial Implementation of a Model System to Provide Military Curriculum Materials for Use in Vocational and Technical Education." Deleted material involves extensive use of military forms, procedures, systems, etc. and was not considered appropriate for use in vocational and technical education.

This supersedes SG 3AZR54550-2-I-1 thru 4, 3 January 1973

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Department of Civil Engineering Training
Sheppard Air Force Base, Texas

SG 3AZR54550-2-I-2

ELECTRICAL PRINCIPLES, CIRCUITS, COMPONENTS, AND TROUBLE ANALYSIS

OBJECTIVES:

This study guide is designed to aid you in becoming familiar with the principles of electricity, the types of electrical circuits and various components. It will develop practical proficiency in trouble analysis of electrical malfunctions common to refrigeration and air-conditioning equipment.

INTRODUCTION:

Have you ever stopped to think what you would be missing if there wasn't any electricity? There wouldn't be any lights, radio, TV, fans or refrigeration, and air conditioning.

It is your job as a refrigeration and air-conditioning specialist to determine if a malfunction is caused by the refrigeration system or the electrical system. Approximately three-fourths of all refrigeration malfunctions are caused by electrical troubles; therefore, a good working knowledge is essential in doing your job.

At first glance this unit of instruction may appear quite lengthy, don't let this stop you from digging in and getting the material. Study it carefully and you will build the sound foundation for success in your career specialty.

STUDY ASSIGNMENT: "Modern Refrigeration and Air Conditioning," paragraphs 7-1 through 7-43.

STUDY NOTES

Paragraph 7-1 through 7-12.

Electricity is a mystery to most people, in fact many people are afraid of it. These paragraphs are an elementary study of the essentials of electricity. They are the things you must know before you can proceed to a futher understanding of electrical units and their operation.

Volts are the pressure units. Amperes are the number of electrons flowing per second in any electrical circuit. You must have both, for together they determine the power. The word amperage means current flow. Electricity has a difficulty in flowing, the term applied to this is called resistance and its units are called ohms. Ohm's Law has been used for decades, you need to understand it and know the relationship between voltage, current and resistance.

Magnetism is a fascinating subject. Motors are possible because of the ability of electricity to create magnetism and the characteristics of this magnetism as it repels and attracts in the coils of a motor. An electric motor uses the changing magnetism of alternating current to produce rotary motion.

Paragraphs 7-13 through 7-19.

There you will find an elementary explanation of magnetism, and how it is used to produce an electric motor. Induction motors are motors that produce motion by inducing magnetism in the rotor.

Paragraph 7-31.

The refrigeration specialist must familarize himself with the power source and motor properties. The motor properties that must match the power source are voltage, cycle, and phase. Before installing equipment always check the power source.

Paragraph 7-32.

Before connecting the electrical power wires to a motor, you should always check its voltage rating and the rating of the power line. If you should connect a 120-volt motor to a 240-volt line the motor will burn out. Always check the voltage at the motor leads with the motor running. Also check the amperage or current draw of the motor, it must agree with the nameplate rating. A motor must always be protected, use the correct size fuse or overload protectors.

Paragraph 7-33.

Line voltage has become of increasing concern to the refrigeration specialist, due to voltage fluctuations caused by the increased electrical demands. Improper line voltages cause many problems. Line voltages can vary from five to ten percent. Line voltage transformers (figure 7-35) are designed to increase or decrease the input voltage to motors as needed.

Paragraphs 7-34 and 7-35.

The catagories of motors using ac are listed on these pages. The applications of each motor is given. You should be knowledgeable of each type of motor and its application.

Paragraphs 7-36 and 7-37.

Split-phase induction motors are used exclusively as a fractional hp motor. It is low cost and simple in operation. It has two starter windings; a start winding and a run winding.

Paragraph 7-38.

The repulsion-start induction-run motor is used on conventional or open systems, study this material carefully.

Paragraph 7-39.

The capacitor-start induction motor is the most popular for use in both conventional and hermetic or sealed systems. This is the motor you should study very carefully as this is the type you will work on most frequently.

Paragraph 7-40.

A refrigeration specialist should become as expert on motors as possible, he must be able to determine the trouble if there is a fault in the motor both mechanical and electrical. He should be able to replace bearings, starting switches, and other parts as necessary. Mounting, pulley alignment, lubrication, and cleaning of motors are very important and should be checked whenever you are working with motors.

Paragraphs 7-41 through 7-43.

Study these figures and paragraphs carefully; they contain valuable information you must know and will use frequently in the performance of your duties.

Hermetic motors will be covered in another unit of study in the course. You may at your own discretion read the information covered to prepare yourself for future study of these systems.

SUPPLEMENTARY INFORMATION

CONSTRUCTION OF MATTER

To understand the nature of electricity, a discussion of matter is necessary. All matter, such as metals, water, rubber, and air is made of small particles called molecules.

Molecules

A molecule is the smallest particle of any compound that can exist and still be the same substance. For example, a molecule of salt is the smallest particle of salt that can exist and still be salt. Let us examine a single molecule of salt more closely. If we were to divide this one molecule of salt, we wouldn't have salt any more. We would have one atom of sodium and one atom of chlorine. See figure 1.

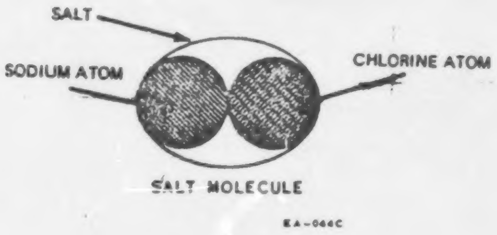


Figure 1. Molecule of Salt

Atoms

Atoms are so small that two hundred million of them placed side by side would only measure one inch. In spite of this, we have a very clear idea of what goes on inside an atom.

Construction of an Atom

An atom is constructed in a manner which greatly resembles the solar system of the sun and earth. Each atom has a core (like the sun) and one or more planets (like the earth) revolving about it.

The hydrogen atom is the simplest of all atoms. It has just one planet revolving about its core, see figure 2. In an atom, the planets are called electrons (negatively charged particles).

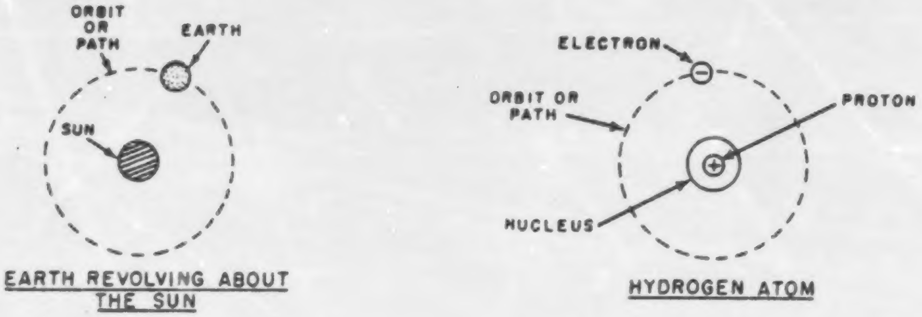

ORBIT
OR
PATH
EARTH
SUN
EARTH REVOLVING ABOUT THE SUN
ELECTRON
ORBIT OR PATH
PROTON
NUCLEUS
HYDROGEN ATOM

Figure 2. Solar System and Hydrogen Atom

These electrons, together with protons (positively charged particles) and neutrons (neither positive nor negative), make up the atoms of which matter is composed. The electrons are in constant motion about the nucleus, see figure 3

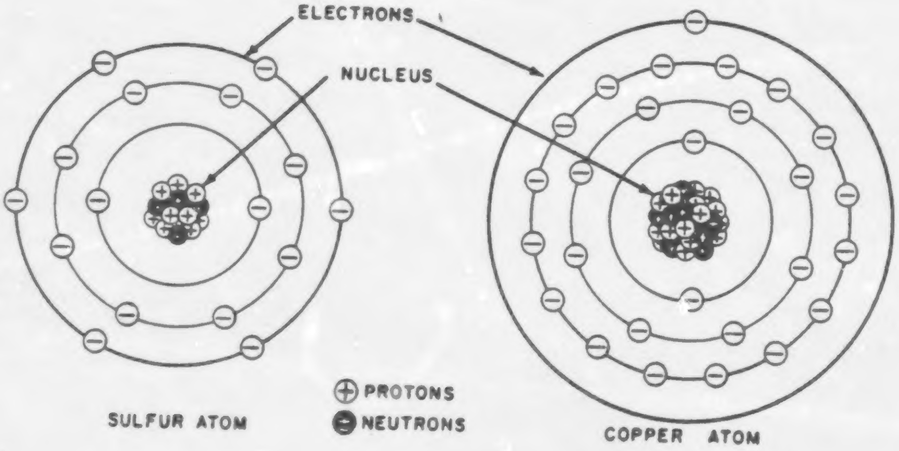

ELECTRONS
NUCLEUS
PROTONS
NEUTRONS
SULFUR ATOM
COPPER ATOM

Figure 3 Construction of an Atom

Some of these electrons are loosely held by the nucleus and will move freely when an electrical pressure is applied. The uniform flow of these electrons is called electric current. If a substance has a large number of free electrons and allows current to flow easily, the substance is called a conductor. Other substances, such as mica, glass, and rubber have few free electrons and prevent the movement of their electrons. These substances are called insulators.

ELECTROMOTIVE FORCE

We are all familiar with the fact that it takes pressure to push water through a hose. In the city water system we have approximately 60 psi of water pressure. This pressure will push a certain amount of water through a 1/2-inch water hose.

It is understandable, then, that to have electricity we must first produce electrical pressure which will force the electrons through the wires and through the electrical appliance. This pressure is called electromotive force, voltage, or difference in potential. These terms all have the same meaning.

Electrical pressure is obtained by converting heat, mechanical and chemical energy into electrical energy. The battery on your car is an example of chemical energy which is converted into electrical energy. The main source of voltage, however, is the conversion of mechanical energy into electrical energy, as in the case of the generator. To generate a voltage mechanically, three things are needed. You must have a conductor, a magnetic field, and relative motion. Combine these three, move the conductors or magnetic field, and voltage will be generated.

Some facts about voltage that you should remember are:

1. The unit of measure for electromotive force (emf) is the volt.
2. EMF is measured with a voltmeter.
3. The symbol for emf is "E."
4. The effect of emf is that it causes current to flow.

CURRENT

The word "current" means motion or movement. Current is the uniform movement of electrons. (The pressure which moves them has already been explained.)

Let's examine a piece of copper wire. The wire appears to be a solid piece of material; however, this wire is made up of millions and millions of electrons. If one extra electron is pushed into one end of the wire, the atom has an extra electron. It will now push this extra electron over to the next atom. This atom will repeat the process until the end of the wire is reached. At the end of the wire the electron will jump to any other object that needs an electron. This is what is happening when you see an electric spark.

It is easy to measure the amount of water flowing in a system. This might be one gallon per second or 50 gallons per second. Where water flow is measured by the gallon, electron flow is measured by the ampere. In the simplest form, an ampere is 6,280,000,000,000 electrons passing a given point in one second. Of course, this figure is not used in practical application, but it does prove that an ampere is a given amount. The symbol for current is "I." The meter used to measure electron flow is the ammeter.

The movement of electrons through a conductor will cause four different effects.

First, current will always cause HEAT. The amount of heat produced depends on the amount of current flowing and the material of the conductor. Copper conductors give very little rise in temperature, while nichrome is used in heating elements. The conversion of electrical energy into heat is used in such devices as electric lights, stoves, and soldering irons.

A second effect of current is CHEMICAL CHANGE. As current passes through impure water it causes a chemical change. An example of this is the breaking down of water into oxygen and hydrogen. This effect of current is also used to plate metals. Another use of chemical change is to charge batteries.

A third effect of current is SHOCK. As current passes through the body it produces an effect known as physical shock. Hospitals use this in the treatment of some illnesses. It has no useful purpose as far as the refrigeration serviceman is concerned; however, it can cause death if you become careless. Under ideal conditions as little as 4/10 of an amp can kill you.

A fourth effect of current is MAGNETISM. Magnetism means the ability to attract iron. Copper will not magnetize, but current through a copper wire will set up a magnetic field about the wire. This magnetic effect of current is used in electrical motors, generators, and electromagnets.

So far, we have been discussing electrical pressure causing electrons to flow. It is reasonable to state that if nothing were to oppose the movement of electrons, there would be excessive current flow.

RESISTANCE

The opposition to the flow of current offered by the conductors and electrical appliances is called resistance. The ohm is the unit of measure for resistance. The meter used to measure resistance is the Ohmmeter.

There are four factors which affect the resistance of a conductor.

One factor affecting resistance is LENGTH. Referring again to the water system, if we had a hose 50-feet long, we would expect a lot of water to flow through it. If the length of the hose were increased to 100 feet, what would happen to the flow? The same thing happens in an electrical conductor. The longer the wire, the higher the resistance and the less current will flow through it.

A second factor affecting resistance is AREA or DIAMETER. The larger the area of the conductor, the greater the flow of electrons.

The third factor affecting resistance is MATERIAL. Any substance in which an electrical pressure can separate large quantities of electrons from their atoms and force these electrons to move in the substance is a good conductor. Silver is the best conductor. When the material of a conductor is changed, the resistance of the conductor changes.

The fourth factor affecting resistance is TEMPERATURE. Temperature is the speed of the molecules in a substance. If the molecules are moving, the atoms are also moving. If the temperatures of the conductor increases, the speed of the atoms increases. This increase in speed makes it more difficult for voltage to separate the electrons from their atoms; consequently, current decreases.

PRINCIPLES OF MAGNETISM

A magnet is an object which has the ability to attract iron. Any object which acquires magnetism when placed in a magnetic field is said to be magnetized. Before an object (such as a steel bar) is magnetized, the molecules point in all directions, as shown in figure 4.

When the steel bar is placed in contact with a magnet, the molecules will be rearranged as in figure 5. The steel bar is said to be magnetized, and thus becomes a magnet.

It is easy to arrange the molecules of soft iron. But when the magnetizing force is removed, its molecules will return to the position shown in figure 4. However, in hard steel, arranging the molecules is more difficult, but the molecules remain aligned.

We can conclude from this that there are two types of magnets, permanent and temporary. Hard steel is used in making permanent magnets, and soft iron is used in making temporary magnets.

In any magnet the ends are called the magnetic poles (north and south). If a magnet is cut into pieces each piece becomes a separate magnet with a north and south pole, see figure 6.

If two magnets are suspended and are free to move, their like poles will repel each other, and their unlike poles will attract each other, see figure 7.

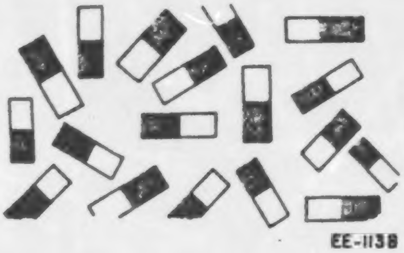


Figure 4. Arrangement of Molecules in an Unmagnetized Steel Bar

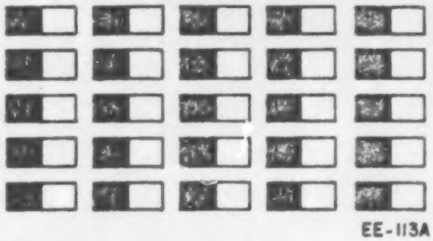


Figure 5. Arrangement of Molecules in a Magnet

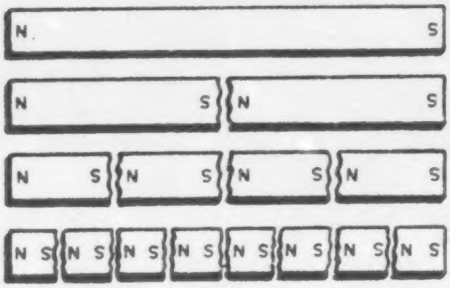
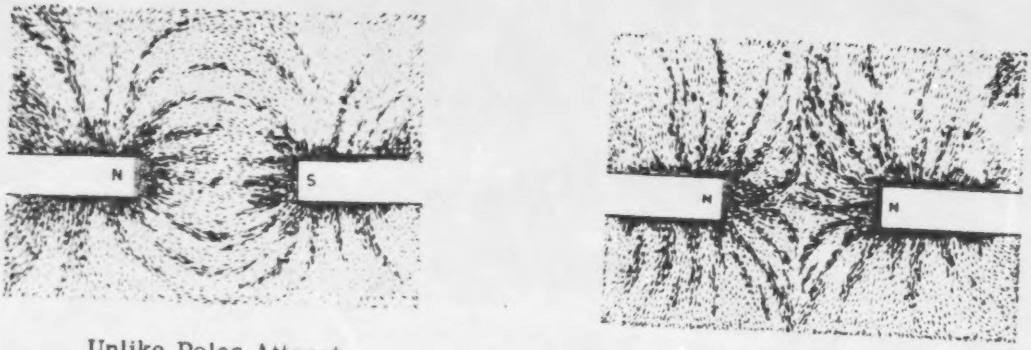


Figure 6. Breaking a Magnet Makes Each Piece a Small Magnet



Unlike Poles Attract

Like Poles Repel

Figure 7. Attraction and Repulsion

Lines of Force

The space around a magnet in which its force may be detected is its MAGNETIC FIELD. The magnetic field is made up of LINES OF FORCE, see figure 8.

When the theory of the magnetic force was proposed, it was believed that magnetic loops, or lines, emerged from N poles and entered S poles as shown in figure 8. The theory founded upon this belief has never been disproved.

Although you cannot see a magnetic field, you can prove that one does exist by placing a bar magnet under a piece of white paper or plastic and sprinkling iron filings on top of the paper as shown in figure 9.

This experiment also proves that magnetic lines of force can pass through plastic or paper. They will pass through all substances, including air. In fact, there is no known substance that will insulate magnetic lines of force.

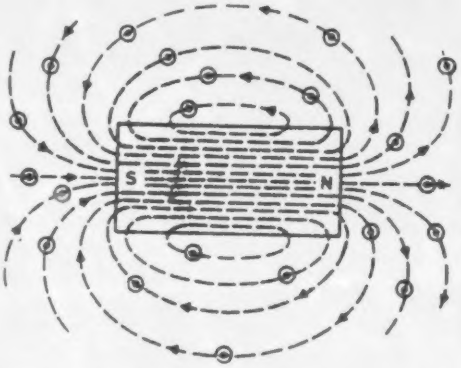


Figure 8. Magnetic Field Around a Bar Magnet

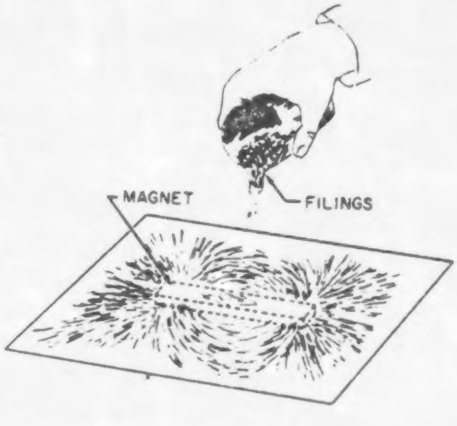


Figure 9. Illustrated Magnetic Field

When a piece of soft iron is placed in the air between the poles of a magnet, the magnetic lines will take the path of least resistance. Consequently, the lines will pass through the piece of iron rather than the air, see figure 10.

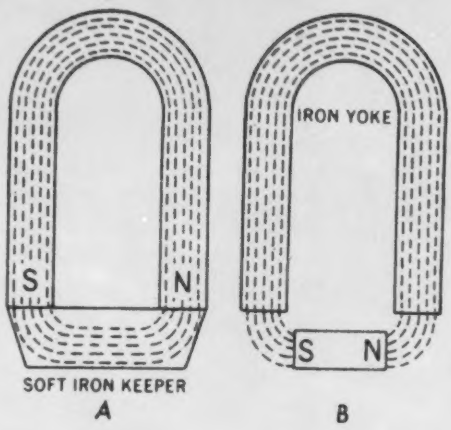


Figure 10. Effects of Soft Iron Bar on a Magnetic Field

Magnetic Induction

When an unmagnetized bar is placed within the magnetic field of another magnet, the lines of force will pass through the unmagnetized bar, see figure 11, aligning its molecules. When the molecules are aligned, magnetism results. This is called induced magnetism.

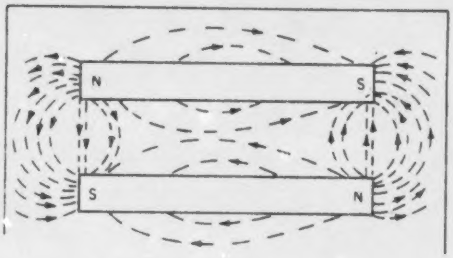


Figure 11. Induced Magnetism

Electromagnetism

Magnetic fields are also produced by electric current, see figure 12. Such fields are called electromagnetic fields and are composed of lines of force like all other magnetic fields. The force of the field is strongest close to the wire or conductor.

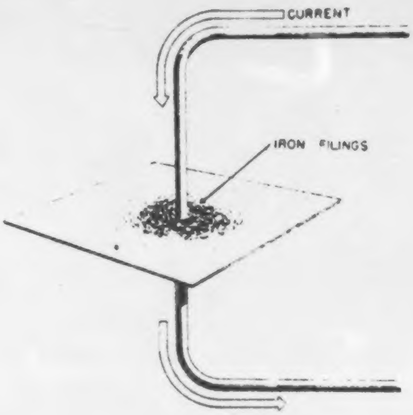


Figure 12. Magnetic Lines of Force Around a Current Carrying Wire

A stronger magnetic field can be obtained by looping the conductor to form a coil as shown in figure 13.

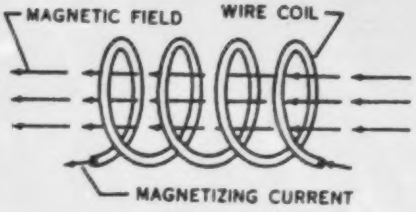

MAGNETIC FIELD
WIRE COIL
MAGNETIZING CURRENT

Figure 13. A Current Carrying Coil has a Magnetic Field

If a coil is wrapped around a bar of iron as in figure 14, the magnetic field becomes still stronger. This is because iron, as has already been stated, offers an easier path for magnetic lines of force than does air, and because the bar becomes magnetized and its lines of force add to those of the coil. The iron bar becomes an electromagnet having polarity and all the characteristics of any other magnet.

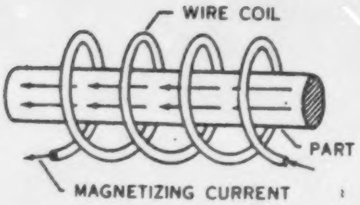

WIRE COIL
PART
MAGNETIZING CURRENT

Figure 14. The Electromagnet

Left-Hand Rule

The left-hand rule for determining the polarity of a coil is illustrated in figure 15.

If you place your fingers around the coil, pointing in the direction of electron flow through the conductor, the thumb will point to the north pole of the coil. It is understandable that reversing the current flow through the conductor will reverse its polarity.

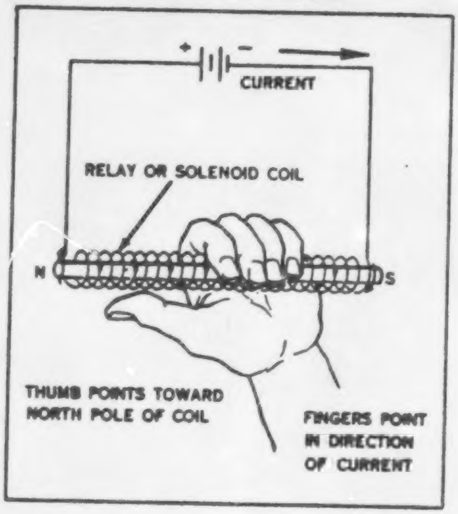

+
-
CURRENT
RELAY OR SOLENOID COIL
N
S
THUMB POINTS TOWARD NORTH POLE OF COIL
FINGERS POINT IN DIRECTION OF CURRENT

Figure 15. Left-Hand Rule for Determining Polarity of an Electromagnet

Three things determine the strength of an electromagnet:

Material in the core.

Number of turns in the coil.

Amount of current through the coil.

As long as current flows in the conductor, the lines of force surround it. But when the current ceases to flow, the lines collapse and the iron bar loses its magnetism. Therefore, it is called a temporary magnet.

ELECTRICAL CIRCUIT

Basic DC Circuits

Direct current (dc) circuits are circuits in which the current flows in one direction only. Alternating current (ac) circuits, which will be discussed in a later section, have current that periodically reverses direction.

An electrical circuit is a closed path in which electrons can flow. The four basic requirements of a circuit are (1) negative conductor, (2) positive conductor, (3) source of power, and (4) unit of resistance.

The negative conductor is the connection made from the negative terminal of the source of power to the unit of resistance.

The positive conductor is the connection made from the unit of resistance to the positive terminal of the source of power.

The source of power or voltage is usually a chemical or mechanical energy converted to electrical energy.

The unit of resistance is the opposition placed in the path of current such as light, fan, motor, and refrigerator.

The four basic parts of the circuit can be seen in figure 16.

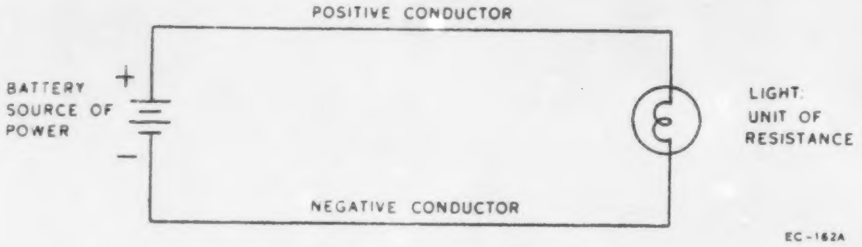


Figure 16. Four Basic Parts of a Circuit

TYPES OF CIRCUITS

Electrical circuits can be divided into three general classifications: series, parallel, and series-parallel.

Series Circuits

A series circuit can be defined as one in which there is only one path through which the voltage can force the current. In figure 17 is a diagram of a series circuit.

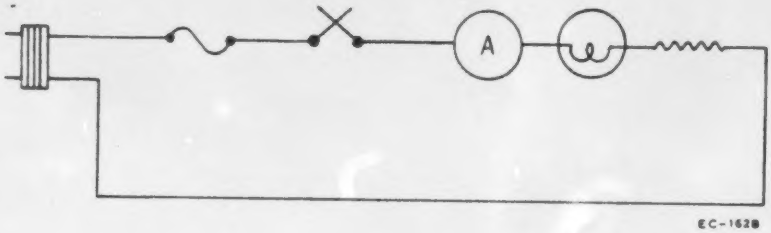


Figure 17. A Series Circuit

CHARACTERISTICS OF A SERIES CIRCUIT. Since there is but one path for the current, all the current is forced through each resistance; consequently, current is the same throughout the circuit.

The second characteristic of a series circuit is that the sum of the voltage drops across each of the resistances should equal the total of applied voltage.

The third characteristic is that the total resistance is equal to the sum of the resistance of each unit.

Parallel Circuits

A parallel circuit is one in which there are two or more paths for voltage to force current through, containing only one unit of resistance in a path, see figure 18

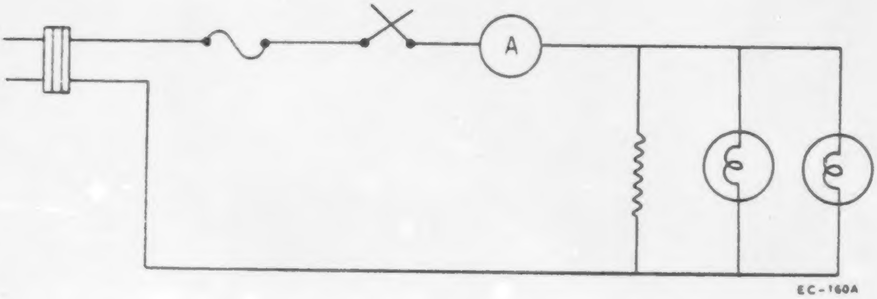


Figure 18. A Parallel Circuit

CHARACTERISTICS OF PARALLEL CIRCUITS. The total current in the circuit is equal to the sum of the currents flowing through all the paths.

The second characteristic is that the voltage across each unit in parallel is the same.

The total resistance, that is, the resistance of the circuit as a whole is less than the smallest resistance in it.

Series-Parallel Circuits

A series-parallel circuit is one in which some units are in series and others are in parallel. A diagram of a series-parallel circuit can be seen in figure 19.

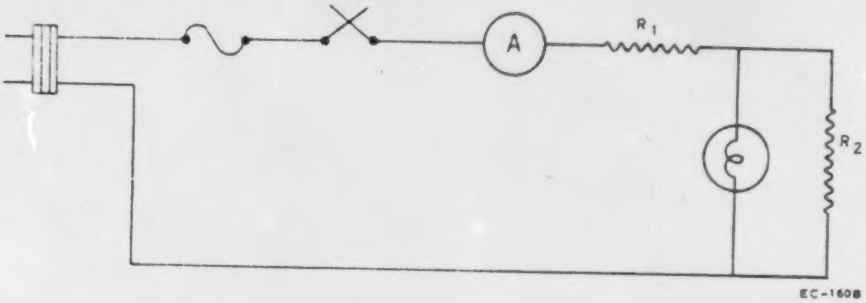


Figure 19. A Series-Parallel Circuit

CHARACTERISTICS OF SERIES-PARALLED CIRCUITS. The characteristics for the series-parallel circuit are a combination of those for the series and the parallel circuits.

Current is the flow of electrons in a closed path. They are forced to flow by applying an electrical pressure. Resistance is the opposition to the flow of electrons.

Four effects of current are heat, magnetism, shock, and chemical change.

Heat, chemical, and mechanical energies can be converted to electrical energy.

Resistance of a conductor is affected by length, size, temperature, and material.

A circuit is a closed path for electrons to flow from a source of pressure, through resistance, and back to the source of pressure.

Fuses and circuit breakers are used to protect the circuit in case of an overload.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano
2. Textbook: Basic Electricity/Electronics, Vol III. Van Valkenburgh, Nooger, and Neville.

ELECTRICAL METERS

Meter Movement

The D'Arsonval meter movement consists of an electromagnet rotating in the field of a permanent magnet, see figure 20.

The current enters at terminal "C" and causes coil "AB" to become an electromagnet. By applying the left-hand rule for coils, you can see that "B" is the north pole and "A" is the south pole. Since unlike poles attract, "A" will be attracted by the north pole of the permanent magnet and "B" will be attracted by the south pole of the magnet, causing the coil to rotate clockwise and the pointer to move clockwise. If the amount of current through the coil is increased, naturally the magnetic field becomes stronger and the amount of rotation will increase.

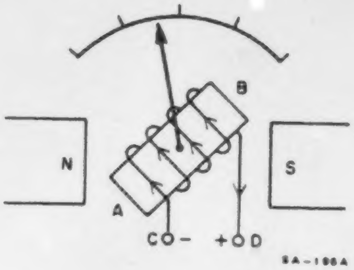


Figure 20. Schematic Drawing of the D'Arsonval Meter Movement

If the direction of current flow is reversed, the coil tends to rotate counterclockwise. Therefore, dc voltmeters and ammeters must be connected into the circuit with proper polarity. The terminals of these meters have their polarity marked.

DC Ammeter

The ammeter is used to measure the amount of current flow in the circuit. Consequently, it will be connected in series with the operating unit as shown in figure 21.

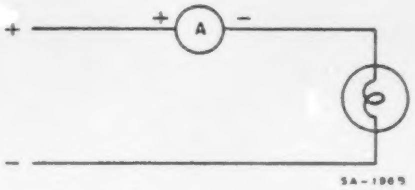


Figure 21. Ammeter Connected in Series with the Unit

The coil of the meter movement is not always capable of carrying the current flow of the circuit. In order to enable the ammeter to measure a greater rate of current flow, it is only necessary to add a bypass for current or a shunt. A shunt is a strip of metal having low resistance. It is connected across the meter terminals to carry most of the current. It allows only a small part of the current to flow through the coil. The shunt may be inside the meter case or it may be connected externally, see figure 22.

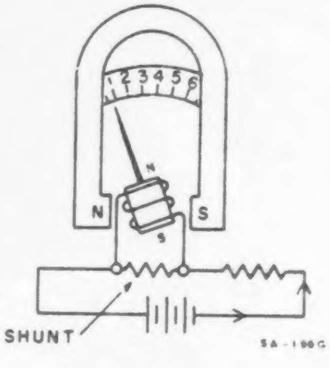


Figure 22. Ammeter Construction

Remember:

An ammeter is connected in series with the unit.

Connect the positive terminal of the ammeter toward the positive side of the circuit. See figure 21.

Know the ammeter current rating and the circuit current before making any connections.

DC Voltmeter

The voltmeter is used to measure the difference in voltage between two points. The voltmeter is connected in parallel to the operating unit.

As you can see from figure 23, the voltmeter is the only unit in a path of current flow. To protect the coil of the meter movement a resistance must be connected in series to it, see figure 24.

The purpose of this resistance is to limit the current flow through the meter movement. Since the resistance of the meter is fixed, the amount of voltage applied to the terminals determines the amount of current flow through the coil, thereby determining the pointer movement.

Remember:

A voltmeter is connected parallel with the unit.

Connect the positive terminal of the voltmeter toward the positive side of the circuit as shown in figure 23.

The range of voltage you are checking.

Ohmmeter

An ohmmeter is used to measure resistance. It contains a battery and a rheostat in series with the coil, see figure 25.

The battery supplies the power to operate the meter movement. Therefore, the main power source must be disconnected when using the meter. Severe damage to the meter can occur if this precaution is disregarded.

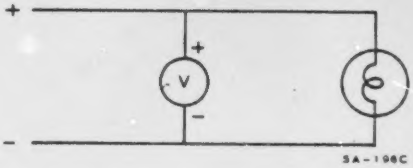


Figure 23. Voltmeter Connected Parallel to the Unit

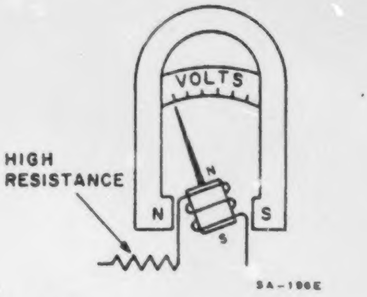


Figure 24. Voltmeter Meter Movement

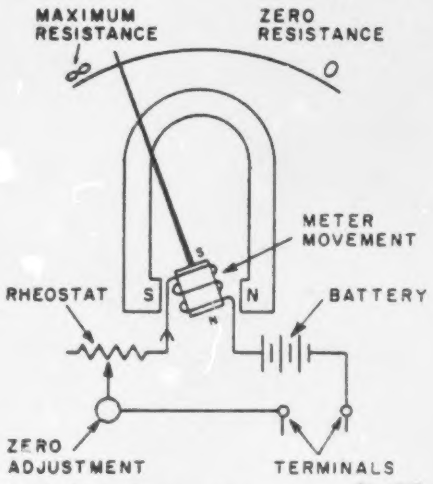


Figure 25. Ohmmeter

Remember:

The ohmmeter has its own source of power. Circuit power must be off.

Adjust the pointer to zero before using the meter. Use the proper range jack for accurate reading.

Multimeter, TS-297/U

The multimeter, TS-297/U, is a meter for measuring ac and dc voltages, direct current, and resistance. To select the desired meter, a SWITCH KNOB is set on OHMS ACV, DEV, or MA, see figure 26.

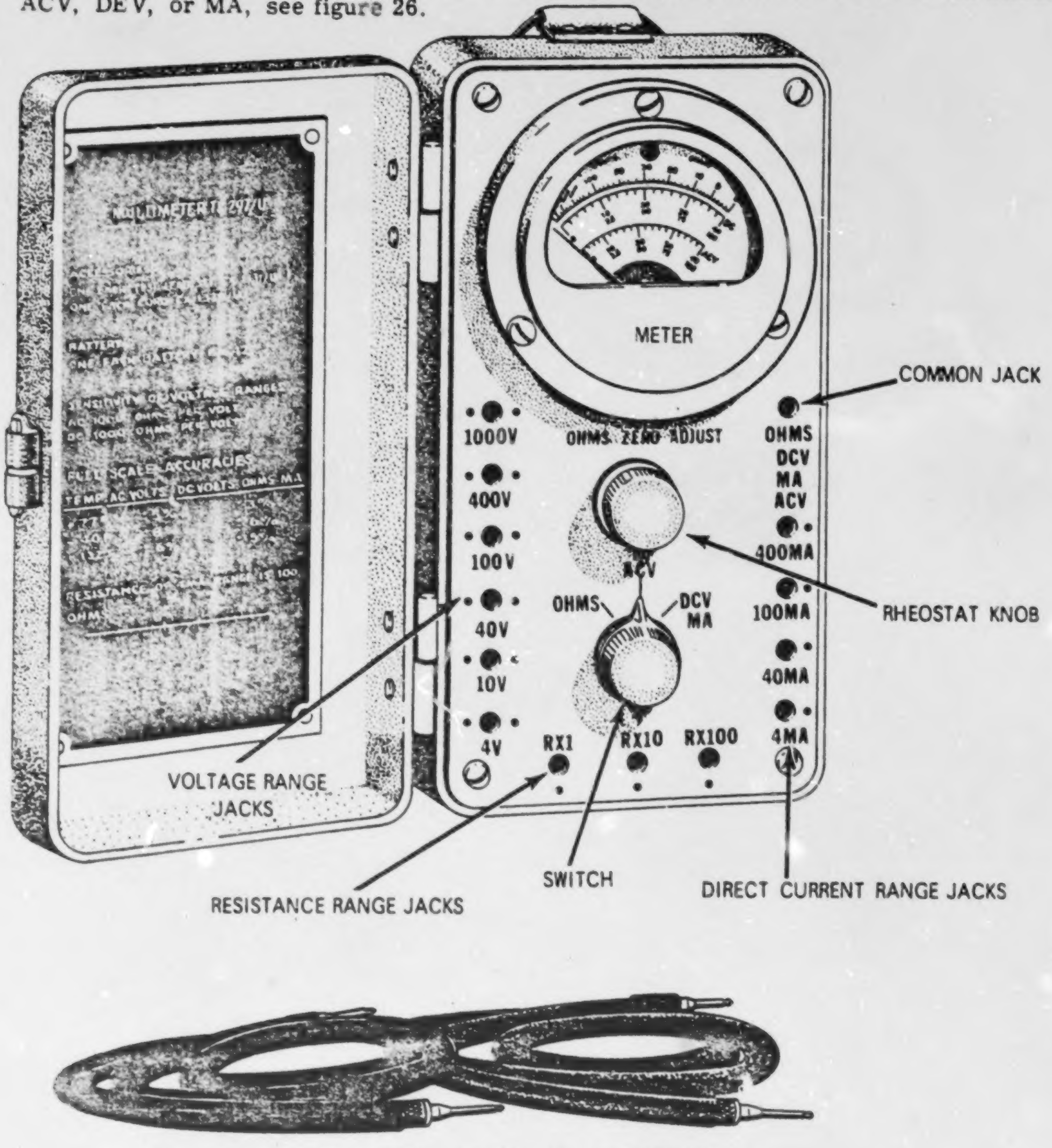

MULTIMETER TS-297/U
BATTERY
SENSITIVITY OF VOLTAGE RANGES
FULL SCALE ACCURACIES
RESISTANCE
METER
COMMON JACK
OHMS ZERO ADJUST
1000V
400V
100V
40V
10V
4V
OHMS
DCV
MA
ACV
400MA
100MA
40MA
4MA
RHEOSTAT KNOB
ACV
OHMS
DCV
MA
RX1
RX10
RX100
VOLTAGE RANGE JACKS
RESISTANCE RANGE JACKS
SWITCH
DIRECT CURRENT RANGE JACKS

Figure 26. Multimeter TS-297/U

The multimeter has a black and a red lead. The black lead is always placed in the common jack, see figure 26 to locate this jack. The red lead is placed in the jack according to the function desired. The 4V through 1000V jacks are for ac or dc voltage measurements. For example, if you wanted to measure a 28V dc power source, the switch knob would be placed on DCV, the black lead placed in the common jack and the red lead placed in 40V.

The R x 1, R x 10, and R x 100 jacks are used for measuring resistance and the 4 MA to 400 MA jacks are used for measuring direct current.

The dial is marked with three scales as shown in figure 27. The scale to be read depends on the switch knob setting and the range jack into which the red lead is placed. The top scale is used for measuring resistance. It ranges from 0 to ∞.

The center scales are used for dc voltage measurements and dc milliamperes. The scale ending in 40 is used when the red lead is in a range jack beginning with "4." The scale ending in 100 is used when the red lead is placed in a range jack beginning with "1," see figure 26 and 27.

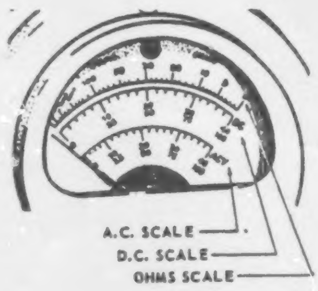


Figure 27. Three Scales on Dial

The lower scale, labeled ac, is used for measuring ac voltage. It also has two sets of calibrations - 0 to 40 and 0 to 100, used in the same way as the dc.

The RHEOSTAT KNOB is used to adjust the meter pointer to 0 when the multimeter is used as an ohmmeter.

Remember:

To prevent damage to the multimeter when measuring voltage, current, or resistance, always start with the highest range to obtain the approximate reading. Then use the lowest range possible as indicated by the reading.

Be sure to read the correct scale.

High voltages are dangerous and may be fatal. Follow posted safety rules.

Shut off power when measuring resistance.

Isolate components for accuracy.

DO NOT LEAVE THE SWITCH ON OHMS WHEN THE MULTIMETER IS NOT IN USE AND THE TEST LEADS ARE INSERTED, BECAUSE ACCIDENTAL SHORTING OF THE TEST PRODS WILL TEND TO DISCHARGE THE BATTERY.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.
2. Textbook; Basic Electricity/Electronics. Vol III. Van Valkenburgh, Nooger, and Neville.

OHM'S LAW

There is a definite relationship between current, voltage, and resistance of any circuit. If the voltage is increased, the current increases proportionately. If the resistance is increased, the current decreases proportionately. This relationship is known as OHM'S LAW. Ohm's law can be stated as follows: The current in a circuit is equal to the voltage divided by the resistance. Mathematically it is written as follows:

$$I = \frac{E}{R}$$

The letter I stands for current; E stands for voltage or emf; R stands for resistance. When voltage is known to be 12V and resistance is known to be 4Ω, these known values are substituted for their corresponding letters in the formula. The formula now reads

$$I = \frac{12V}{4\Omega}$$

Current may be found by dividing 4 into 12. It will equal 3 amperes.

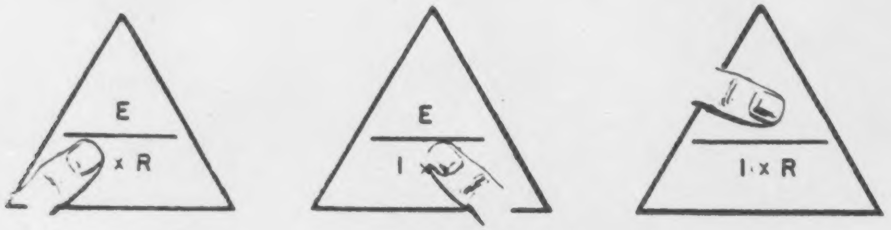
The equation can be converted to read $R = \frac{E}{I}$. Let us suppose that the known factors are 12 volts and 3 amperes. The known values are again substituted in the formula

$$R = \frac{12V}{3A}$$

By dividing we find the resistance to be 4 ohms.

Still another equation is available, $E = IR$. Suppose that the known factors are 3 amperes of current and 4Ω of resistance. After substitution, the formula is $E = 3A \times 4\Omega$. By multiplying in this instance, voltage is found to be 12 volts.

These three equations will enable you to find any one of these three factors (voltage, current, or resistance) if you know the other two. An easy way to remember the three relationships is to place them in a triangle as shown in figure 28.



TO FIND I (AMPERES) PLACE THUMB OVER I AND DIVIDE E BY R AS INDICATED

TO FIND R (OHMS) PLACE THUMB OVER R AND DIVIDE AS INDICATED

TO FIND E (VOLTS) PLACE THUMB OVER E AND MULTIPLY AS INDICATED

E:VOLTS

I:AMPERES

R:OHMS

Figure 28. Ohm's Law Chart

If you place your finger over the quantity you do not know, the relative positions of the other two known factors will tell you what to do.

TROUBLESHOOTING ELECTRICAL CIRCUITS

Trouble with a refrigeration unit often involves electrical problems. The refrigeration specialist should be able to troubleshoot electrical circuits. We can simplify his problem by determining if the malfunction is electrical or mechanical. Troubleshooting can be defined as a "systematic method of locating faults in an electrical circuit."

Wiring Diagrams

A wiring diagram of the electrical system on which you are working should be obtained so that you will understand the type of circuits and the units involved. A picture of the circuit will aid in troubleshooting and making operational checks of the units.

TYPES OF TROUBLES

An important fact to remember is that there are only three types of troubles; opens, shorts, and low power.

Opens

An open circuit is one that has a break somewhere in it. This break could be located in the wire, in the switch, fuse or in the unit of resistance. In fact, it would exist anywhere. Naturally if there is a break there can be no current flow; consequently, the unit of resistance would not be operating, see figure 29.

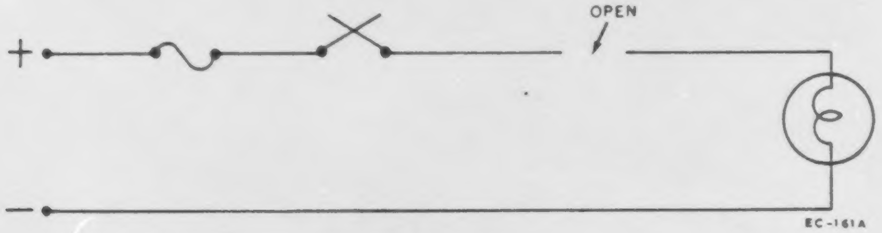


Figure 29. Open Wire

There are four different testers that can be used to find an open. These are the voltmeter, continuity tester, ohmmeter, and test light.

LOCATING OPENS. The exact location of an open can be found by using the voltmeter. You should, first of all, understand what a voltmeter indicates in a normal operating circuit. Figure 58 illustrates normal voltmeter readings throughout the circuit.

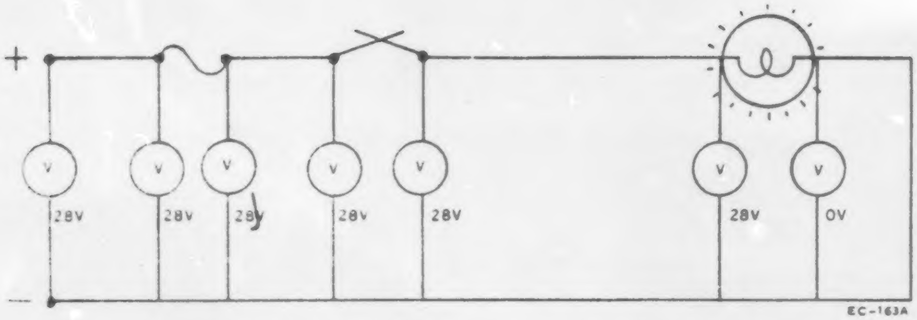

+
−
V
28V
28V
28V
28V
28V
28V
0V
EC-163A

Figure 30. Normal Voltmeter Readings

A voltmeter connected positive to negative should always indicate the difference in voltage across the two points. A voltmeter connected negative to negative or positive-to-positive should not give a difference in electrical pressure, see figure 30. Readings other than these are considered abnormal. Exact location of an open can be found in the positive or negative parts of the circuit between a normal and an abnormal reading.

Figure 31 illustrates a voltmeter being used to find an open in wire A-4. Note that wire A-4 is in the positive part of the circuit.

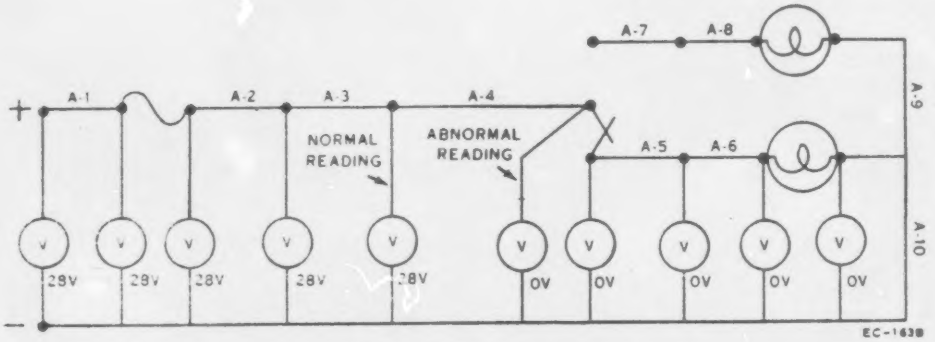

A-7
A-8
A-9
+
A-1
A-2
A-3
A-4
A-5
A-6
NORMAL READING
ABNORMAL READING
A-10
V
28V
28V
28V
28V
28V
0V
0V
0V
0V
0V
−
EC-163B

Figure 31. Locating an Open in Wire A-4

In figure 32, a voltmeter is being used to locate an open in the negative part of the circuit. The exact location is wire A-6.

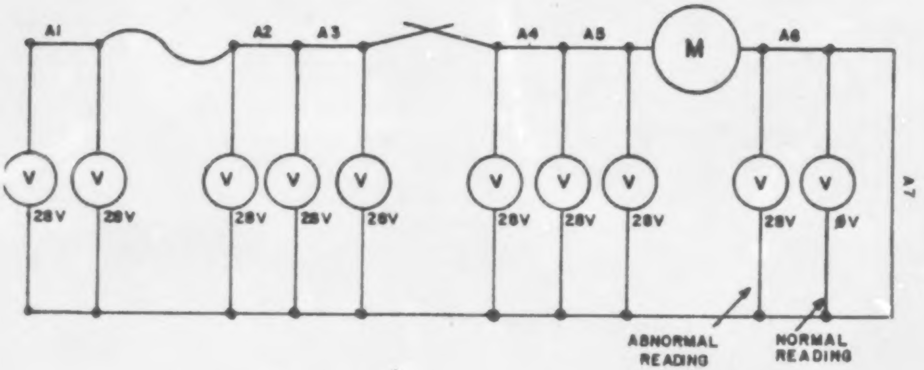

A1
A2
A3
A4
A5
M
A6
A7
V
28V
28V
28V
28V
28V
28V
28V
28V
28V
ØV
ABNORMAL READING
NORMAL READING

Figure 32. Locating an Open in Wire A-6

The same procedure is used in troubleshooting an open with a test light; however, a test light will not give an indication of the amount of voltage present, All you know is that there is enough current available to burn the light.

Opens can also be found by using an ohmmeter or a continuity meter. Power must be off and the circuit isolated when using continuity tester. In figure 33 an ohmmeter is being used to locate an open in wire A-6.

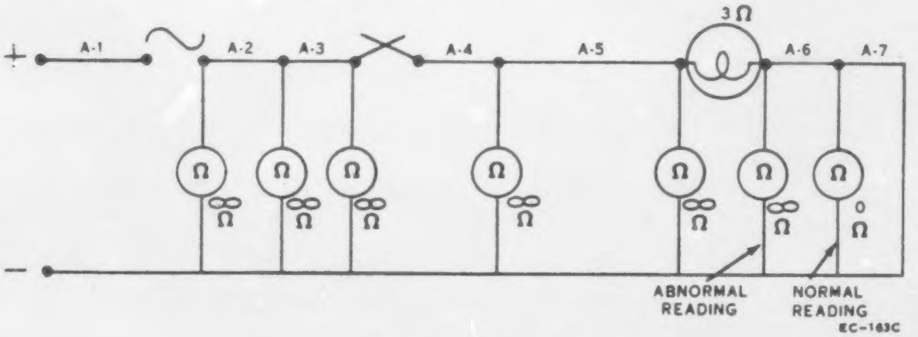

+
−
A-1
A-2
A-3
A-4
A-5
3 Ω
A-6
A-7
Ω
∞ Ω
∞ Ω
∞ Ω
∞ Ω
∞ Ω
∞ Ω
0 Ω
ABNORMAL READING
NORMAL READING
EC-163C

Figure 33. Locating an Open with an Ohmmeter

In figure 33 you will notice that the ohmmeter does not register continuity all the way through the circuit; the open is found between the continuity reading (0 Ω) and the last infinity reading (∞).

Shorts

A short means that there is contact where there should not be contact; consequently there is current flow where there should not be current flow. Indications of shorts are units operating that should not be operating, blown fuses, and tripped circuit breakers.

Direct Short

In the case of a direct short, a negative lead is in contact with a positive lead, bypassing the unit of resistance.

From figure 34, you can see that current in this situation will take the path of least resistance. The excessive current flow will cause the fuse to blow, or if the protective device happens to be a circuit breaker, the circuit breaker will trip, opening the circuit.

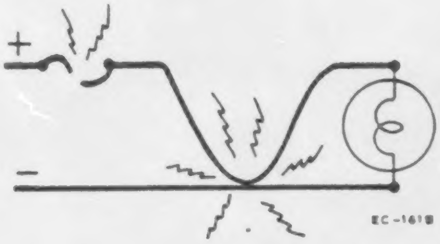


Figure 34. Direct Short

LOCATING DIRECT SHORTS. Some kind of a continuity tester, such as the ohmmeter, continuity meter, or continuity light, should be used in locating direct shorts. The positive leads should be isolated and the testing device connected across the isolated leads. Notice in figure 35, an ohmmeter is being used to locate contact between isolated positive leads and the negative lead. Only the ohmmeter connected to A-4 lead indicates continuity (0 Ω); therefore, A-4 lead is shorted to the negative side of the circuit providing a short cut for current flow.

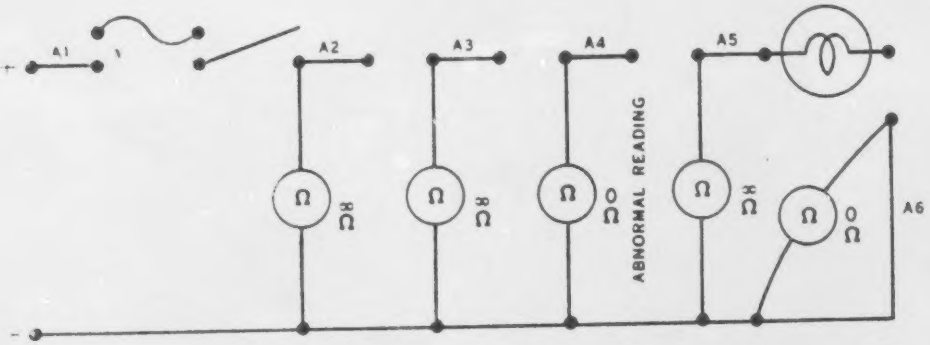


Figure 35. Locating a Direct Short

Cross Shorts

Whereas the direct short is contact between the positive lead of a circuit and the negative lead of a circuit, the cross short is caused by the positive leads on independent circuits coming in contact with each other.

66

During an operation check, a cross short is indicated by two independent units operating from the same switch. In figure 36, positive lead A-8 is touching positive lead A-3. Even though the switch which controls L_2 is open, there is a complete path for current flow from A-8 to A-1; consequently, L_2 burns.

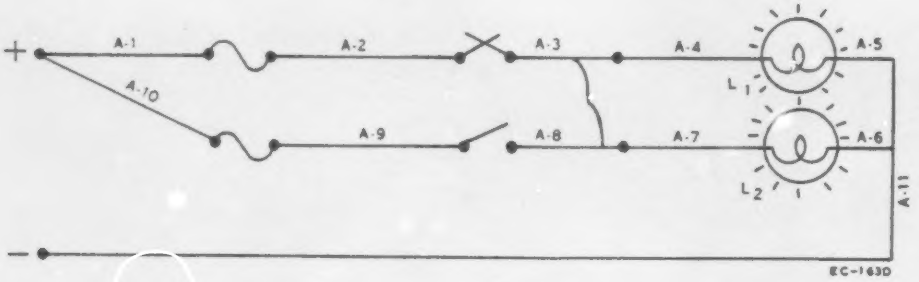


Figure 36. Cross Short

LOCATING CROSS SHORTS. The same testing devices and procedures are used in locating cross shorts as were used in locating direct shorts. Power must be off and the positive leads of both circuits isolated, see figure 37.

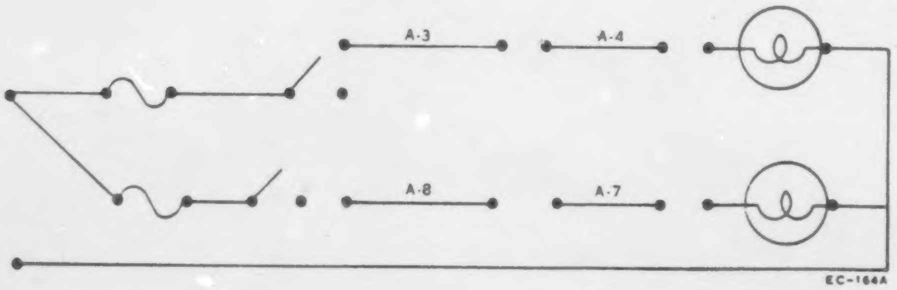


Figure 37. Probable Leads Isolated

After both circuits are isolated, the testing device is connected across the probable leads, such as A-3 to A-7, A-3 to A-8, A-4 to A-8, or A-4 to A-7. Note that any of these combinations would have the same effect. In figure 38, the ohmmeter shows the cross short to be between A-3 and A-8.

61

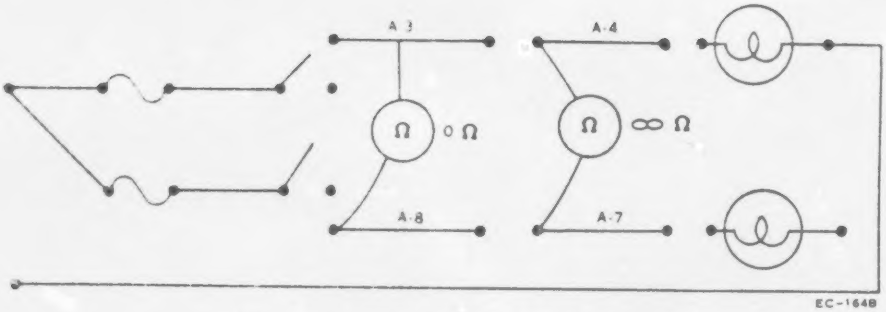


Figure 38. Locating a Cross Short

A shorted switch is one that fails to break contact when it is placed in the OFF position. The effect of a shorted switch is that the unit operates continuously. Any testing device can be used to determine whether the switch is defective. In figure 39, an ohmmeter indicates that the switch is shorted.

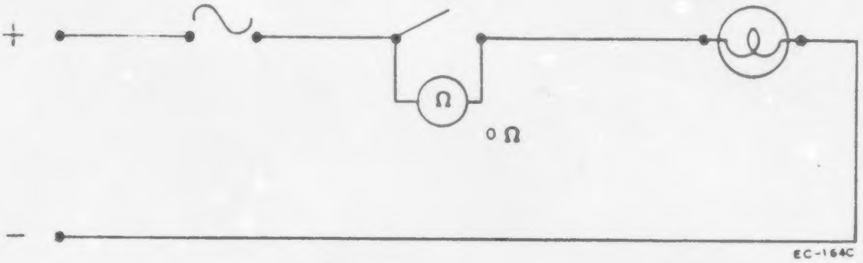


Figure 39. Checking for a Shorted Switch

Low Power

This condition is often found in old buildings or in areas where the electrical load has been increased without increasing the size or number of electrical circuits. A low power condition is indicated by sluggish operation of units and dim lights.

If a low power condition is suspected, all the electrical units on the circuit should be turned on. This should create maximum current flow. Voltage drops across the units should be compared with total voltage available. Figure 40 shows a line loss check.

If a low power condition is discovered, the electrical lead must be reduced or a new circuit installed.

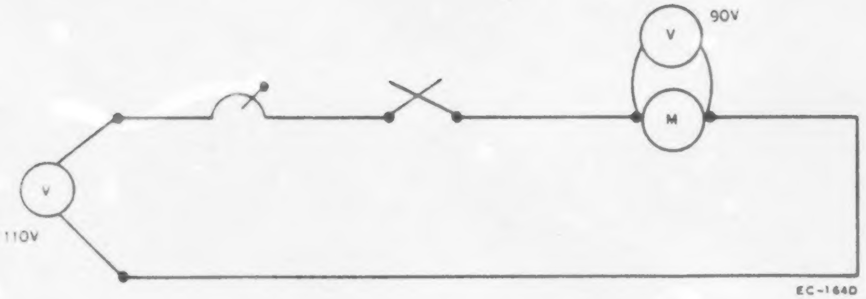


Figure 40. Voltage Drops Should Equal Total Voltage

Summary

Permanent and electromagnets are used in meter movements. Meters used by the refrigeration specialist are the dc and ac voltmeters, the ammeter, and the ohmmeter.

Polarity must be observed when connecting ammeters and voltmeters in a circuit. Power must be off when connecting an ohmmeter in a circuit.

The multimeter can be used as an ohmmeter, an ammeter, and a voltmeter.

Troubleshooting is a systematic means of locating malfunctions in a circuit.

The three types of troubles are: opens, shorts, and low power.

Opens prevent the flow of current, whereas a short allows it to flow where it is not wanted. Low power causes sluggish operation of units.

The testing devices are the voltmeter, continuity meter, ohmmeter, continuity light, and test light.

Continuity devices must be used in circuits where the power is off and the circuit isolated. Voltmeter and test light are used in circuits where the power is left on.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.
2. Textbook; Basic Electricity/Electronics. Van Valkenburgh, Nooger, and Neville.

ALTERNATING CURRENT

Definition of AC

Alternating current may be defined as a current which changes direction at regular intervals.

It may also be defined as a current which increases in value at a definite rate from zero to a maximum positive value, and again decreasing to zero, as shown in figure 41.

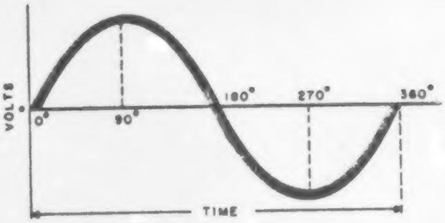


Figure 41. AC Voltage Curve

Generation of AC

To generate a voltage mechanically, either ac or dc, three things are needed: (1) a magnetic field, (2) conductors, and (3) relative motion. Combine these three, move the conductors or magnetic field, and a voltage will be generated.

A simple ac generator consists of a single turn coil or wire, a permanent magnet, two sliprings, and two brushes. Each end of the coil of wire is connected to a slipring. The two sliprings are on the end of the rotor and this rotor is mounted between the poles of the magnet so that it is free to rotate on its axis. External connections to the sliprings are made by means of the brushes that are held stationary by the insulated brush holder and make continuous contact with the sliprings, see figure 42.

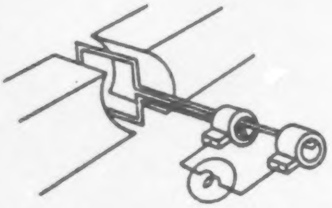


Figure 42. Simple Generator

Generators are our primary source of ac. All mechanical generators generate ac; however, dc generators convert ac to dc through the use of a commutator and brush assembly.

The Sine Wave

If you make a graph of the voltage induced in the conductor at various points, you will obtain an interesting curve, shown in figure 43. Plot the various points in degrees along the horizontal axis and the height of the voltage induced along the vertical axis. Use the horizontal axis as reference for zero voltage. Consider the voltage induced in one direction as positive and that in the opposite direction as negative.

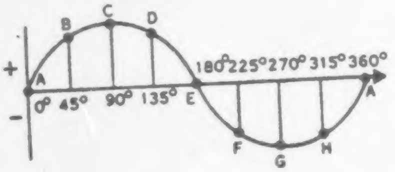


Figure 43. Graph of Induced Voltage

An Alternation

By studying the sine wave in figure 43, an alternation might be explained as a generation of voltage from zero to maximum and back to zero in only one direction. In figure 43. it would be represented between points A to E, or 180 degrees represent the positive alternation. E to A in figure 43 represents the negative alternation.

The Cycle

In electricity, the ac cycle is represented by the following symbol ∿. Again study figure 43 for an explanation of the cycle. A to A (360 electrical degrees) represents one cycle of alternating current or voltage. A further explanation of the alternation and cycle can be seen in figure 44.

Frequency

The number of times each cycle occurs in a period of time is called the frequency. The frequency of an electric current or voltage specifies the number of times a cycle recurs in one second. The rate at which the current changes direction of flow is twice the frequency of the alternating current. If 120 reversals of current occur each second, the frequency of the alternating current is 120/2 or 60 cycles per second.

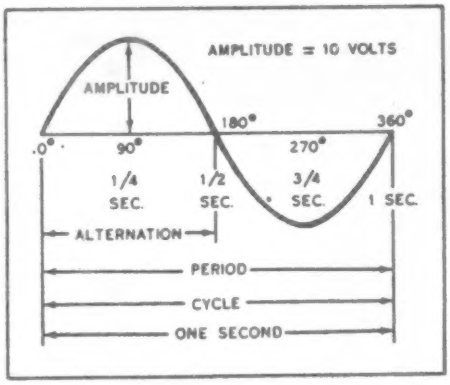


Figure 44. AC Cycle and Its Components

You have learned that current flows from negative to positive. For dc this is easily shown on a graph with a straight line. Alternating current also flows from negative to positive; however, polarity of conductors in an ac circuit is constantly changing. With sixty-cycle current, the polarity of the conductors will change 120 times per second.

Most large ac generators are designed so that the magnetic field (an electromagnet) rotates causing the lines of force to move across the stator coils, inducing a voltage in the stator coils.

Speed of commercial alternators is very closely controlled in order to keep the frequency cycles per second (CPS) constant. Frequency of ac is standardized to 60 cps in the United States. Many foreign countries use 50-cycle current.

For a picture explanation of generation of ac sine waves, alternation, cycle and frequency study figure 45.

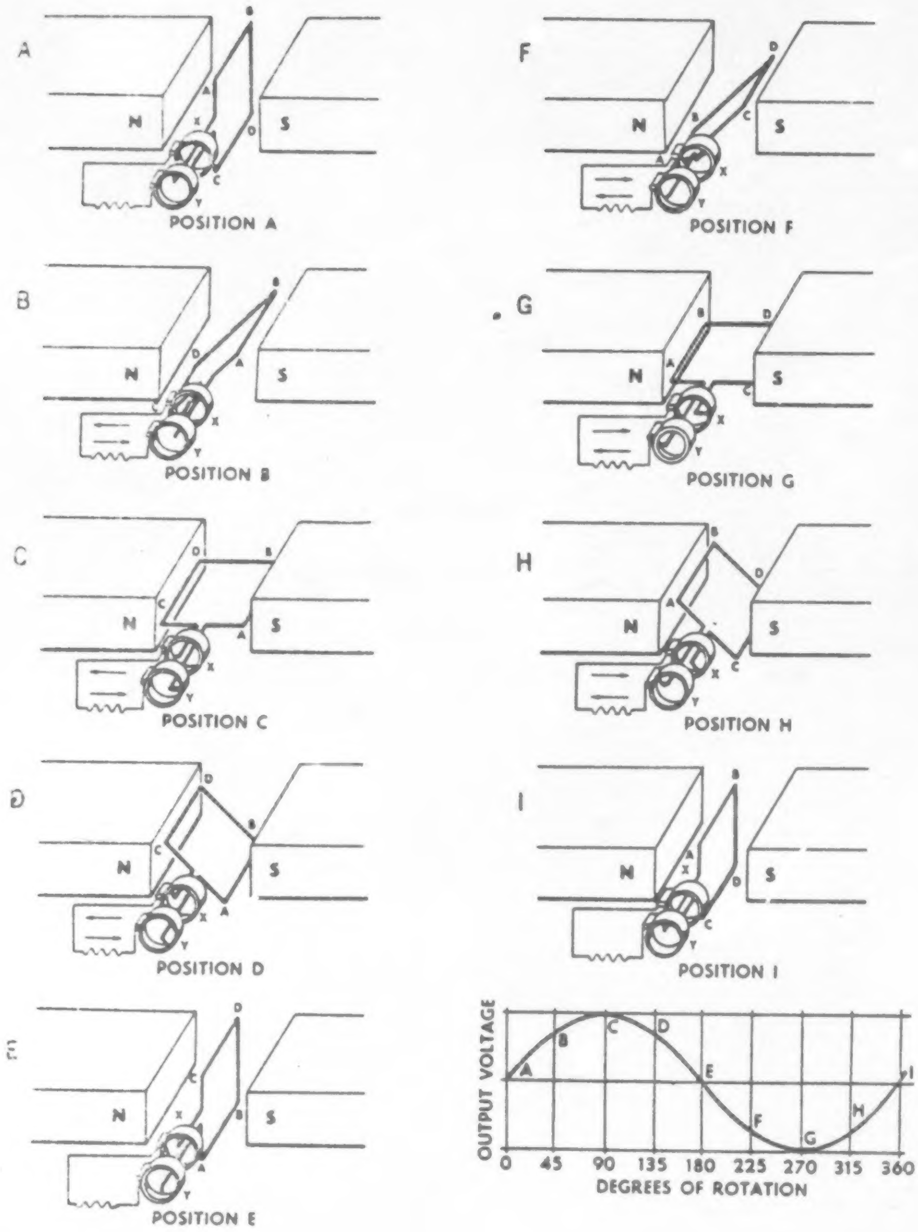

A
N
S
X
Y
A
B
C
D
POSITION A
B
POSITION B
C
POSITION C
D
POSITION D
E
POSITION E
F
POSITION F
G
POSITION G
H
POSITION H
I
POSITION I
OUTPUT VOLTAGE
0
45
90
135
180
225
270
315
360
DEGREES OF ROTATION

Figure 45. Generation of a Sine Wave

Phase of Current and Voltage

When current and voltage pass through zero and reach maximum values at the same time, current and voltage are said to be in phase, see figure 46.

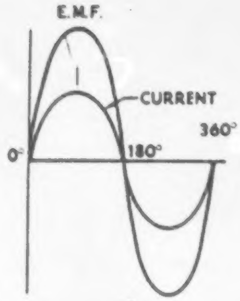


Figure 46. Current and Voltage in Phase

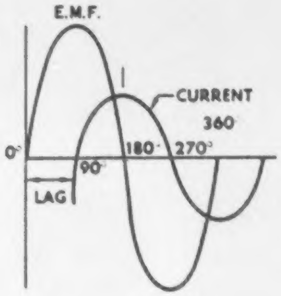


Figure 47. Effect of Inductance

REACTANCE

Alternating current circuits in addition to a power source, conductors, and resistance, may also contain components which produce reactance.

When an alternating current flows through a coil of wire, the rise and fall of the current flow, first in one direction, then in another, sets up an expanding and collapsing magnetic field about the coil and induces a voltage in it which is opposite in direction to the applied voltage and a current flow that opposes any change in the alternating current. This property of a coil to oppose any change in current flowing through it is called inductance.

The opposition to the flow of current which inductance puts in a circuit is called inductive reactance. In a purely inductive circuit, the current reaches a maximum value later than the voltage, LAGGING the voltage by 90°, or one-quarter of a cycle. (Degree of lag may vary.) See figure 47.

Capacitive Reactance

Another important property in ac circuits, besides resistance and inductance, is capacitance. Capacitance is represented by a capacitor. Any two conductors separated by a nonconductor constitute a capacitor. In any electrical circuit, a capacitor serves as a storehouse for electricity.

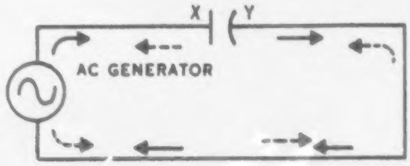


Figure 48. Capacitor in an AC Circuit

When an alternating current is impressed on the circuit, the charge on the plates constantly changes. In figure 48 the electricity must flow first from Y clockwise around to X, then from X counterclockwise around to Y.

Although no current flows through the insulator between the plates of the capacitor, it is always flowing in the remainder of the circuit between X and Y. In a circuit, in which there is only capacitance, current LEADS the applied voltage as contrasted with a circuit in which there is inductance, causing current to lead the voltage. See the effect of capacitance in figure 46.

Capacitance offers resistance to any change in voltage. The opposition caused by a capacitor is called capacitive reactance.

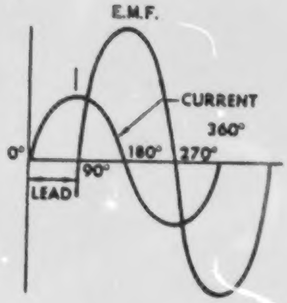


Figure 49. Effect of Capacitance

TRANSFORMERS

When electricity first came into use, Mr. Edison held patent rights on the dynamos which were the power sources. These dc machines usually served an area of about a mile and a half radius because beyond this distance, line loss was too great. Since dc cannot be transformed, power was generated at the same voltage (about 110 volts) that was used in the homes and shops.

While dc was in use, and the existing patent rights were in force, experiments with ac were being performed. It was discovered that for commercial purposes, ac held many advantages.

1. Alternating current, ac, could be transformed--voltages could be stepped up or stepped down by use of a transformer.

2. Because ac could be transformed, smaller transmission lines could be used, and ac could be transmitted over longer distances more economically than dc.

The term "transform" means to change. An electrical transformer is used to change the electrical characteristics of voltage and current. The use of transformers is widespread. Our everyday lives involve the use of many transformers, most of which are never seen by us.

Transformer Operation

In studying characteristics of current, you have learned that around any conductor carrying current, there is a magnetic field, and that three things are required to generate voltage mechanically. They are:

1. A conductor.
2. A magnetic field.
3. Movement of the conductor across the magnetic field, or movement of the magnetic field across the conductor.

These characteristics and principles make operation of a transformer possible.

A transformer consists of three main parts, see figure 50. They are:

1. The primary coil - the coil to which the voltage is applied.
2. The secondary coil - the coil from which the voltage is taken.
3. The core which may be iron or air serves to provide a path through which the magnetic lines of force travel.

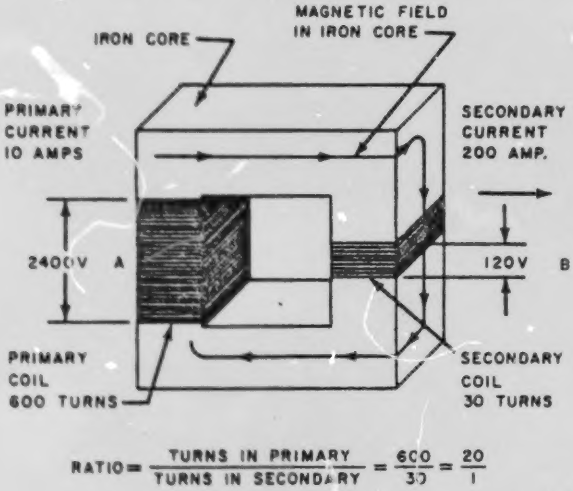

IRON CORE
MAGNETIC FIELD IN IRON CORE
PRIMARY CURRENT 10 AMPS
SECONDARY CURRENT 200 AMP.
2400V A
120V B
PRIMARY COIL 600 TURNS
SECONDARY COIL 30 TURNS
RATIO = TURNS IN PRIMARY / TURNS IN SECONDARY = 600/30 = 20/1

Figure 50. Transformer Construction

If an ac source of voltage is applied to the primary coil, a magnetic field will build up and collapse with each alternation. The lines of force from the magnetic field of the primary coil move across the secondary coil of the transformer, inducing a voltage in this coil. (A magnetic field is moving across a conductor.) The core provides a path for the magnetic field to travel through and may consist of iron or air.

A direct ratio between the number of turns of wire in the primary coil and turns of wire in the secondary coil exists. If there are more turns of wire in the secondary coil voltage will be increased, or stepped up. If the secondary coil has fewer turns of wire than the primary coil, voltage will be decreased, or stepped down. To be more specific, if a transformer has a ratio of one turn on the primary to four turns on the secondary, secondary voltage will be four times greater than primary voltage.

The secondary coil of a transformer may have more than two electrical connections, or "taps," so that more than one voltage may be obtained from one transformer, as shown in figure 51. This transformer is referred to as a multitap transformer and may be a combination step-up and step-down transformer.

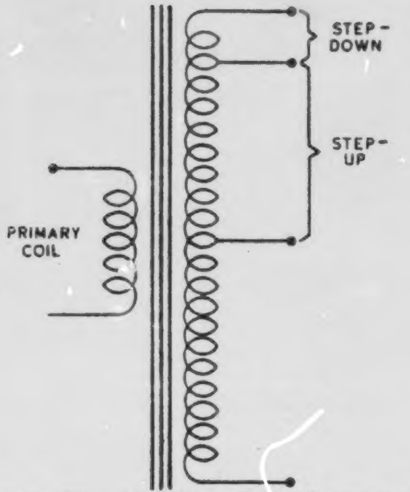


Figure 51. Multitap Transformer

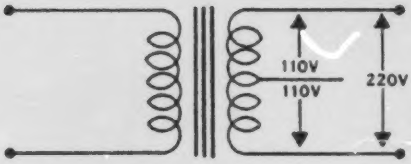


Figure 52. Center-Tap Transformer

The center-tapped transformer is a multitap transformer and is used to obtain two voltages, as shown in figure 52. Center-tapped transformers are used to provide voltages of 110 and 220 volts in our homes and businesses.

PHASING OF ELECTRICAL POWER SYSTEMS

Single-Phase Power

Frequently, we encounter the terms "single phase" and "three phase" when referring to electrical power. To the observer, single- and three-phase transmission lines differ little. Since electricity is an abstract thing, the easiest way to explain phasing of electrical power systems is to explain the generation of power.

You have noted that, as a conductor moves through a magnetic field, a voltage is induced in that conductor. Figure 53 shows a single conductor moving through a magnetic field set up by a two-pole magnet. As the conductor rotates, the maximum number of lines of force are cut as the conductor passes the pole pieces of the magnet, approaching one from the top, the other from the bottom, and alternating current is produced.

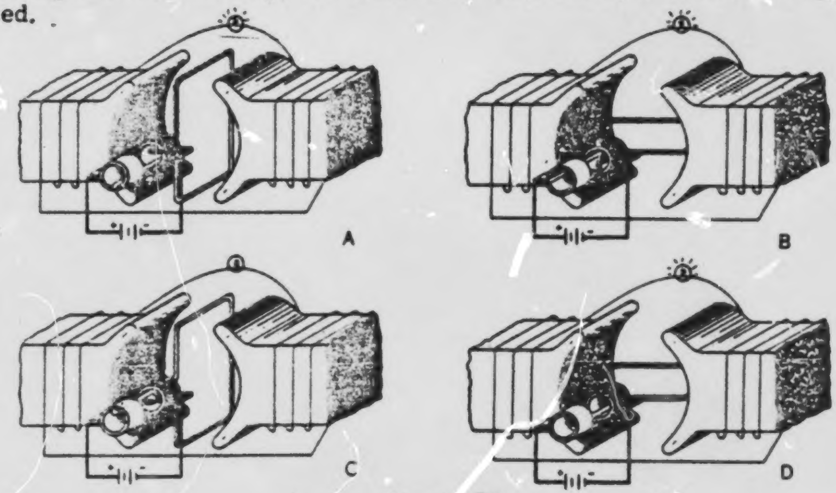


Figure 53.

The output voltage, if plotted on a graph, would be the sine waveform for ac, see figure 54.

In this case the conductor would have to make one complete turn to produce one complete cycle of ac. This single conductor moving past the magnetic pole pieces produce a single waveform which we refer to as single-phase ac. Note that two wires are required to transmit single-phase power.

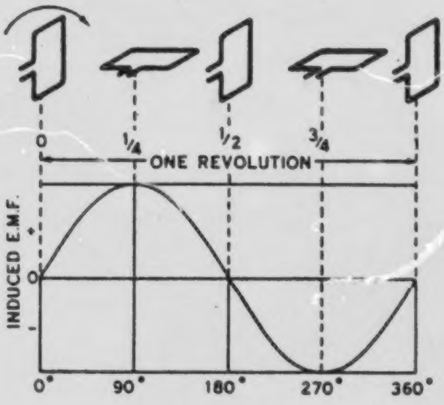


Figure 54.

Three-Phase Power

To generate three-phase power, three conductors, spaced 120 electrical degrees apart, share the same magnetic field, see figure 55. Since the three conductors cannot cut the maximum number of lines of force at the same time, three waveforms, or phases are generated.

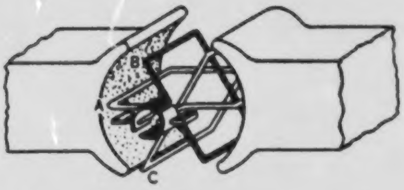


Figure 55.

Figure 56 shows sine waves for three-phase ac.

It would appear that six conductors would be required to transmit three-phase power, however, it has been learned that phases can be made to share conductors and three conductors can efficiently conduct three-phase power.

The primary reason for using three-phase power is for efficient transmission of power and operation of electrical motors. Three-phase motors are simple, rugged, and require little maintenance.

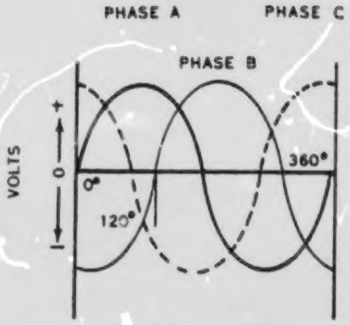


Figure 56. Output of a Three-Phase Alternator

Three-Phase Transformer

Practically all power in the United States is generated as 60 cycles, three-phase alternating current and is supplied at the point of use as single-phase or three-phase alternating current. Voltages available at the point of use depend somewhat on the type of transformer connection.

The transformer we are concerned with is WYE connected. The wye connection is extensively used, see figure 57, and is commonly referred to as a three-phase, four-wire system.

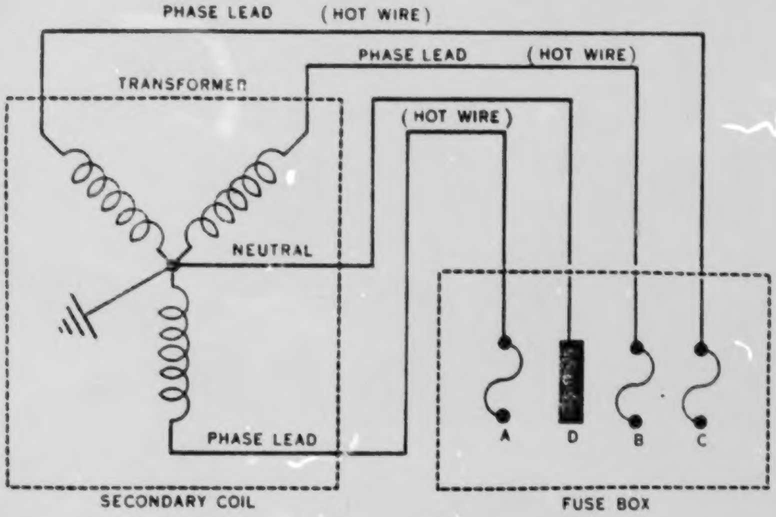


Figure 57 Four-Wire System

The neutral wire allows single-phase, 120 volts. From the neutral wire to any phase lead, 120-volt single-phase is available. Across all three-phase leads, 208-volt three-phase is available.

Voltmeter readings with the wye connected secondary would be:

A - B = 208 volts	Neutral - A = 120 volts
B - C = 208 volts	Neutral - B = 120 volts
C - A = 208 volts	Neutral - C = 120 volts

Note that when the neutral wire is used with any combination of A, B, or C, 120 volts are available. Any combination of A-B, B-C, or A-C will provide 208 volts of single-phase ac power. Three-phase power is obtained using A, B, and C.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.
2. Textbook; Basic Electricity/Electronics. Van Valkenburgh, Nooger, and Neville.

FUNDAMENTALS OF THREE-PHASE MOTORS

Three-phase motors are simple in construction and relatively low in initial cost. The most common types of 30 motors are the squirrel-cage induction motors and the wound rotor induction motor. These two types of motors vary only in the construction of the rotor. Three-phase motors are also referred to as polyphase motors. Three-phase motors can be broken down into three basic parts: (1) stator, (2) rotor, and (3) endbells.

Stator

The frame is made of cast iron or cast steel into which is pressed a laminated silicon steel core. The core is laminated to reduce "Eddy Currents," which is a loss due to stray currents. This core is constructed with semiclosed slots which hold the field windings. The field windings are made up of a number of varnished insulated coils, which are 120° (electrical) apart. These coils are insulated from the core with treated paper called fish paper. The coils are connected to form three separate windings. These windings are connected in either a wye or delta arrangement which will be explained later in this study guide. The field windings and the core together make up the stator or stationary part of the motor. Figure 58 shows the parts of a stator.

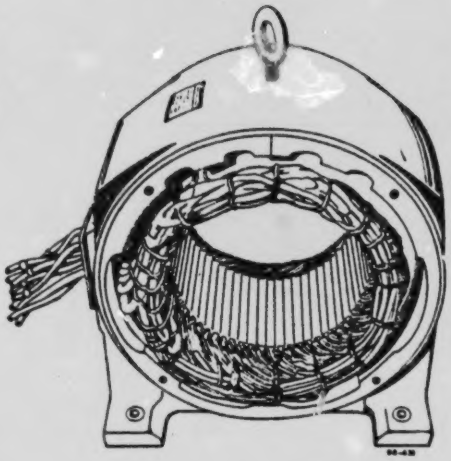


Figure 58. Three-Phased Stator

The kind of rotor used inside of the three-phase stator determines the type of motor. There are two types of rotors, the squirrel-cage rotor and the wound rotor.

Squirrel-Cage Rotor

The squirrel-cage rotor consists of a laminated silicon steel core, rotor bars, and end rings, mounted on a shaft. In the most recent types, the rotor bars are cast into place on an angle called skew. The skew effect increases the torque of the motor. The end rings short circuit or connect the rotor bars together. When one rotor bar is energized all of them are energized. The rotor bars and end rings together make up a squirrel-cage winding. Fan blades are added on the end of the rotor to assist in providing adequate ventilation for cooling, see figure 59.

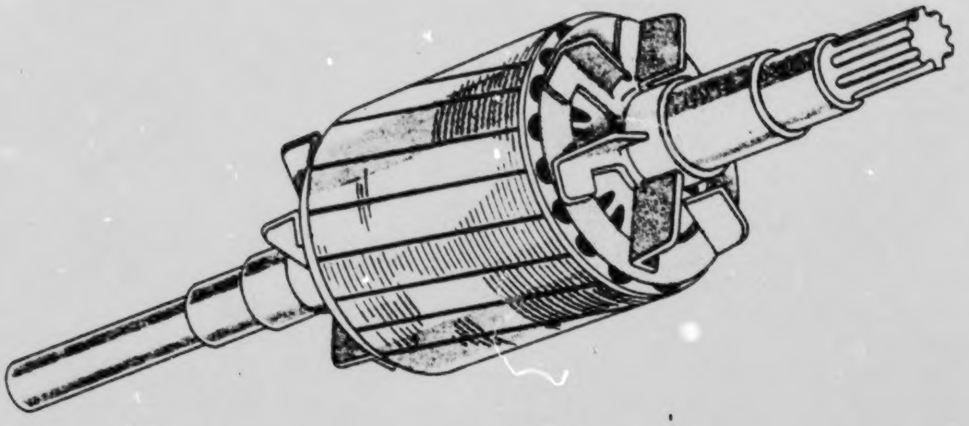


Figure 59. Squirrel-Cage Rotor

Wound Rotors

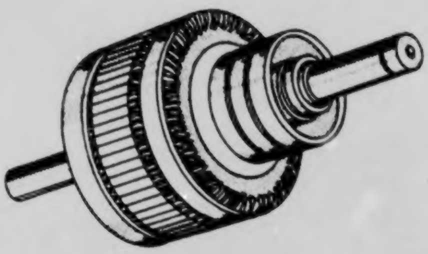


Figure 60. Three-Phased Wound Rotor

The wound rotor has a laminated silicon steel core mounted on a shaft. A rotor winding is wound around the core. The rotor windings are made of coils similar to those used in a stator. Each coil is made up of a number of turns of insulated copper wire. The windings are connected like those of the stator, wye, or delta. When the rotor is connected for wye operation one end of the windings are connected together in the center and the other end connected to sliprings mounted on the shaft. Brushes ride on the sliprings and are connected externally to resistors for variable speed control. When connected for delta operation, the windings are internally connected into a delta configuration and three leads are connected to the sliprings. Wound rotor types of three-phase motors are used where a low starting current and high starting torque is desired without an external starting device, see figure 60.

Endbells

The endbells serve three functions: (1) house the bearings, (2) support and align the rotor and shaft, and (3) complete the frame of the motor.

OPERATION

The most common types of motors used today derive their name from the type of rotor used, operating principle, and their starting mechanism. The major type of motor that you will be working with is called the squirrel-cage induction motor. The term squirrel cage is used because the rotor looks like the exercise wheel used inside a squirrel cage. The term induction refers to the principle of operation which will be studied in this section.

To operate an induction motor, two requirements must be met: (1) a rotating magnetic field must be set up in the stator and (2) a magnetic field must be present in the rotor.

To explain how the magnetic fields are created, a study of the basic three-phase motor will enable you to view the step-by-step process of starting a magnetic field to rotate.

The stator of a three-phase motor is wound with three sets of poles (windings) placed 120 electrical degrees apart, see figure 61.

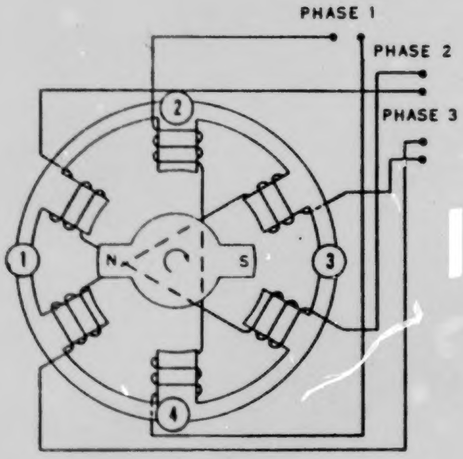


Figure 61. Three-Phased Windings 120 Degrees Apart

Phase 1 is 120 electrical degrees from phase 2. Phase 2 is 120 electrical degrees from phase 3, which is 120 electrical degrees from phase 1. When the three-phase alternating current is applied to the windings, what appears to be rotating magnetic field will be created, a study of the three-phase ac sine wave as current flows through the motor and its effect is necessary.

Figure 62 shows the stator and entering current of three-phase power. Note that phase 1 is at maximum and phases 2 and 3 are below maximum but equal. This condition will cause phase 1 and its poles to set up a strong magnetic field, while phases 2 and 3 set up weaker magnetic fields.

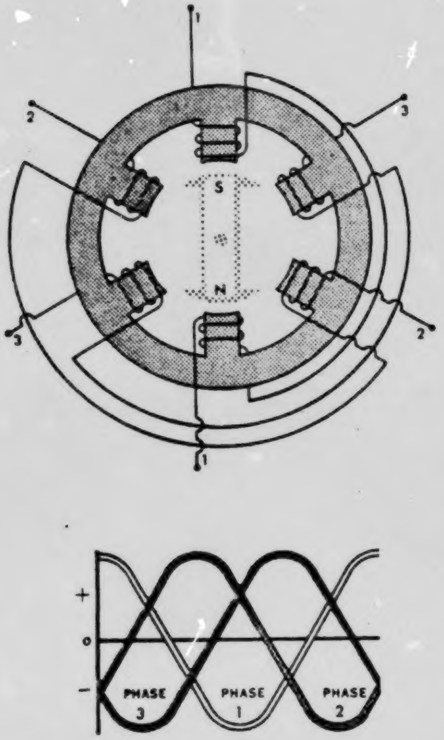


Figure 62. Current Flow in Phase 1 Sets Up Strong Field.

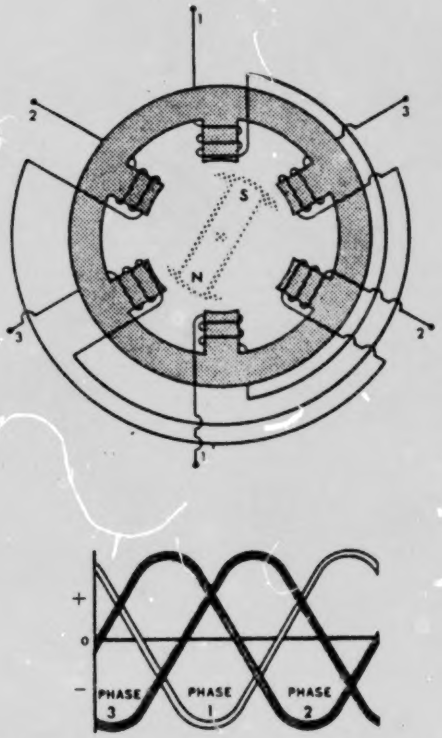


Figure 63. Current Flow in Phases 1 and 3. One and 3 now have strong field.

Figure 63 shows the sine wave and current 22.5 electrical degrees later. Now phase 1 and phase 3 are equal, but opposite and phase 2 is at zero. Phase 2 does not have a magnetic field. The magnetic field is now shifted from its original position [illegible] is now between poles 1 and 3.

Figure 64 shows the relationship after the current shifts another 22.5 electrical degrees. The magnetic field is now strongest in phase 3 and phase 1 and 2 are equal but below maximum.

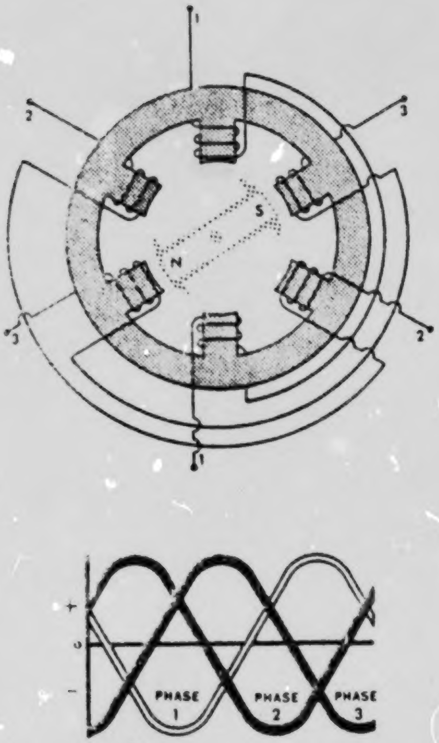


Figure 64. Current applied to phase 3 creates a strong magnetic field there.

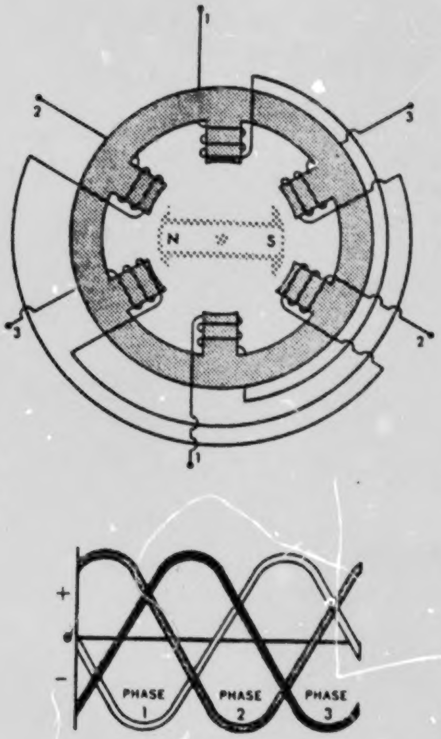


Figure 65. Phase 2 and 3 now each have current flow and a magnetic field.

Figure 65 shows another shift along the sine wave and finds that poles of phases 2 and 3 have set up and share a common magnetic field, while phase 1 is at 0 with no magnetic field.

As the current continues to alternate, the magnetic field will alternate with it. Each change that occurs in the current will create a change in the magnetic field. When this current is applied to motor windings, it sets up an alternating magnetic field which follows the changes in applied current.

The alternating magnetic field in the stator will cut across the copper bars in the rotor, inducing current in them. As the rotor current is induced, a magnetic field will develop around the rods. The magnetic field in the rotor reacts with the magnetic field in the stator producing a torque, causing the rotor to turn.

The superb starting torque of a three-phase motor makes it ideal for application on equipment that requires high torque such as large fans, compressors, and large pumps.

Slip

The time lag between the speed of the rotating magnetic field (synchronous speed) and the rotor speed is called slip. Normal slip is 2 to 5 percent of synchronous speed. If slip increases, the torque (twisting effect of the shaft) increases. However 25 percent slip is called stall point and the rotor stalls or locks. This is normally caused if the motor is overloaded. To figure the percent of slip, synchronous speed must be figured. The formula for synchronous speed is:

Example:

$$\text{RPM} = \frac{\text{frequency} \times 120}{\text{number of poles}}$$

$$\text{RPM} = \frac{60 \times 120}{4}$$

$$\text{RPM} = \frac{7200}{4}$$

$$\text{RPM} = 1800$$

The synchronous speed for a four-pole motor is 1800 RPMs. A data plate located on the stator will give the motor speed (shaft speed) as 1725 RPMs. With these two figures slip can be determined as follows.

$$\text{\% of slip} = \frac{\text{synchronous speed} - \text{rotor speed}}{\text{synchronous speed}} \times 100$$

$$\text{\% of slip} = \frac{ss - rs}{ss} \times 100$$

$$\text{\% of slip} = \frac{1800 - 1725}{1800} \times 100$$

$$\text{\% of slip} = \frac{75}{1800} \times 100$$

$$\text{slip} = 4.1 \text{ percent}$$

Normally you can obtain the RPM of a motor from the data plate. However, in some cases, the data plate will be missing from the motor. If the motor is operational a tachometer can be used to determine the speed of the shaft.

Motor Connections

A three-phase motor has both internal and external connections. The internal connections determine whether the three sets of stator windings are connected delta or wye. The external connections are made with leads which are brought out to the terminal box of the motor. These leads provide a means of connecting the motor to a source of power.

Internal Connections

The two main types of internal connections used in three-phase motors are the wye and the delta.

The symbol for a wye connected motor is the symbol Y . Figure 66 is a schematic diagram of a wye connected motor for high voltage.

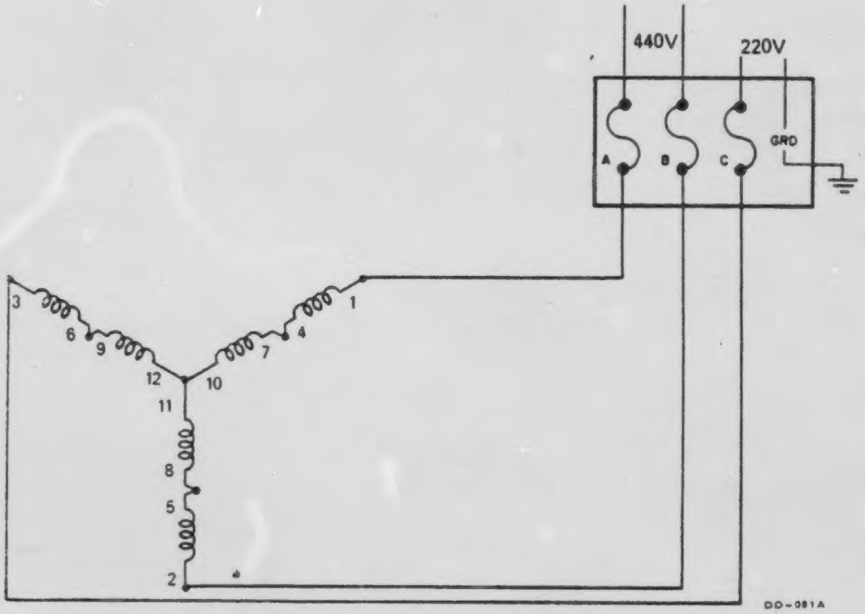


Figure 66. 440-Volt Circuit Diagram

NOTE: The schematic diagrams shown do not illustrate the true position of the coils in the stator.

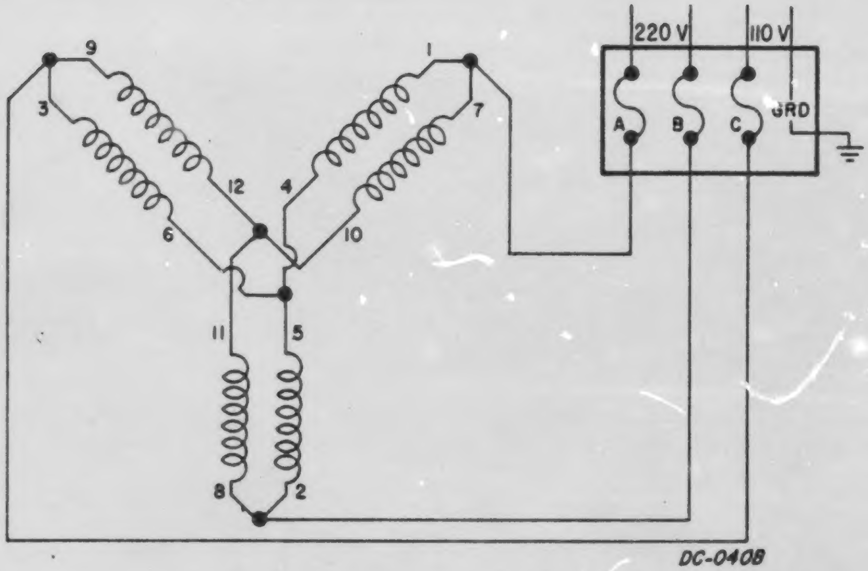

220 V
110 V
A
B
C
GRD
9
3
12
6
1
7
4
10
11
5
8
2
DC-040B

Figure 67. 220-Volt Circuit Diagram

Figure 67 shows a schematic diagram of a wye connected motor for low voltage.

The symbol for a delta connected motor is the Greek letter delta Δ.

Figure 68 shows a schematic diagram of delta connected motor for high voltage.

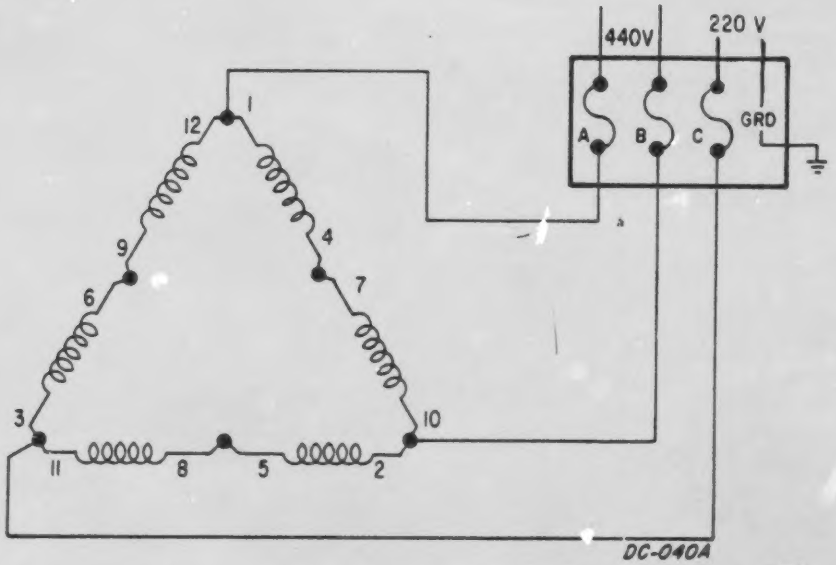

440V
220 V
A
B
C
GRD
1
12
4
9
7
6
3
10
11
8
5
2
DC-040A

Figure 68. 440-Volt Circuit Diagram

Figure 69 shows a schematic diagram of a delta connected motor for low voltage.

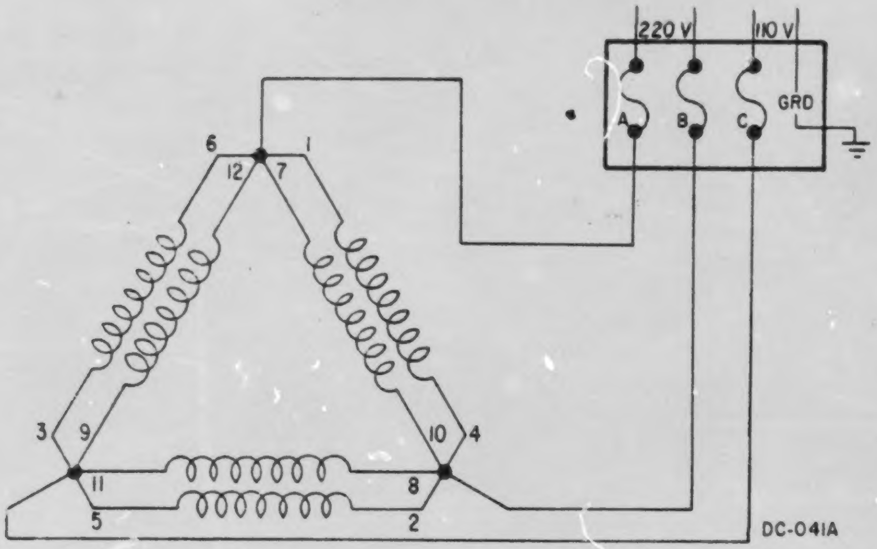

220 V
110 V
A
B
C
GRD
6
1
12
7
3
9
10
4
11
8
5
2
DC-041A

Figure 69. 220-Volt Circuit Diagram

To determine the direction of rotation of a three-phase motor, it is normally started before the load is connected. If the rotation is incorrect, you can change any two power leads to reverse the rotation of the motor. Figures 70 and 71 show the schematic representations.

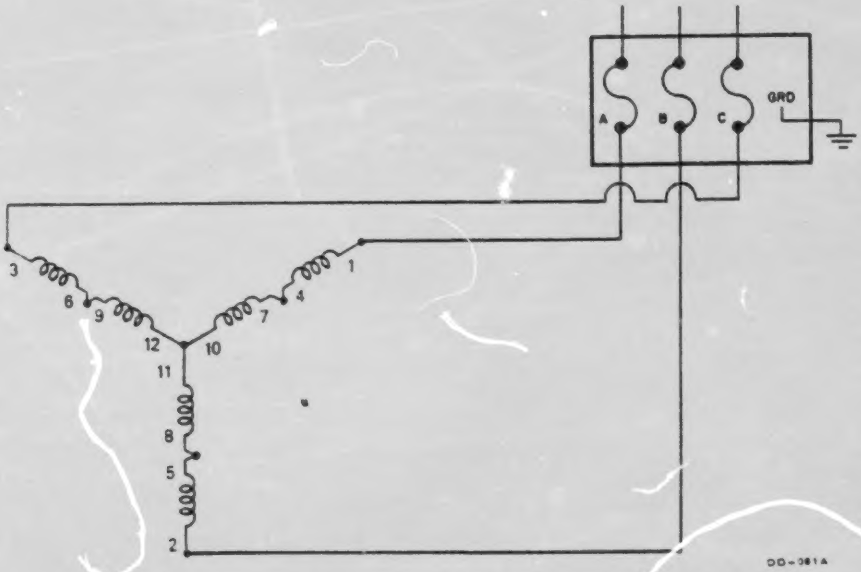

A
B
C
GRD
3
6
9
12
1
4
7
10
11
8
5
2

Figure 70. 440-Volt Circuit Diagram For Wye Connected Motor

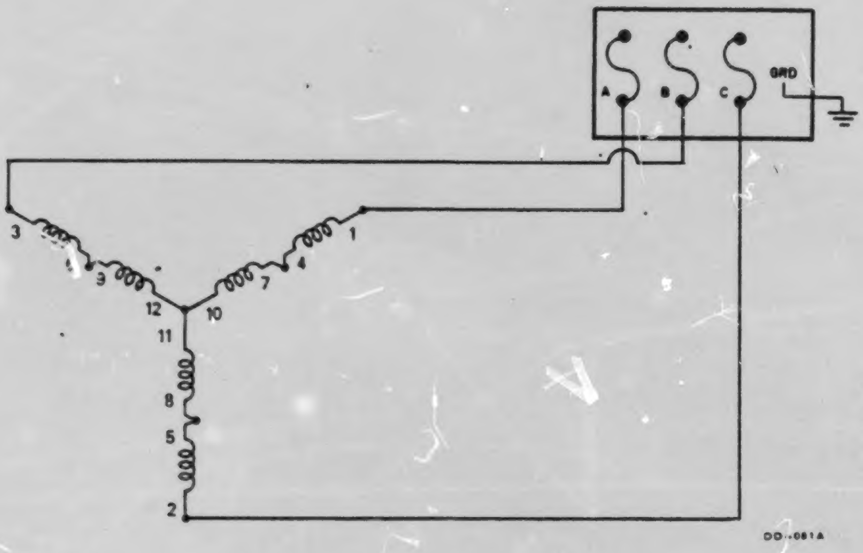


Figure 71. 440-Volt Circuit Diagram for Reversing Direction of Rotation

FUNDAMENTALS OF SINGLE-PHASE MOTORS

Motors may be classed according to their construction features. The two general classes to be covered in this study guide are the commutator motors and induction motors. Both of these classes of motors have a stationary field which is energized with alternating current.

Induction Motors

SPLIT-PHASE MOTORS. Split-phase motors are usually just fractional horsepower and are used to operate such devices as washing machines, small pumps, dryers, and blowers.

Basically, a split-phase motor is constructed the same as a three-phase motor. It has a stator, rotor, and two endbells. The windings are located and connected differently than they are in a three-phase motor. A centrifugal switch has been added to the rotor and one endbell, see figure 72. A rotating part of the centrifugal switch is located on the rotor and a stationary part (containing a set of contacts) is located in the endbell. The purpose of this switch will be explained later in this study guide.

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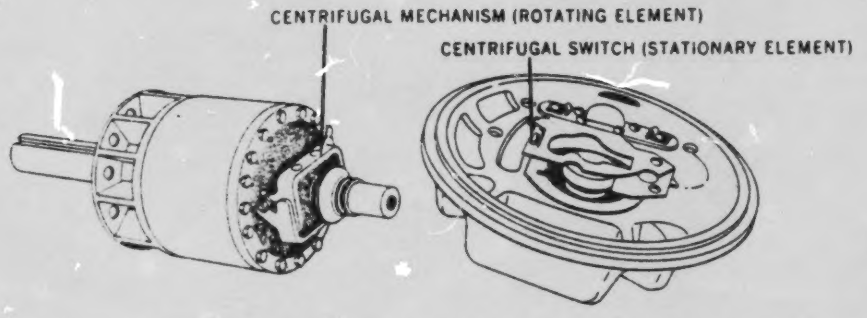

CENTRIFUGAL MECHANISM (ROTATING ELEMENT)
CENTRIFUGAL SWITCH (STATIONARY ELEMENT)

Figure 72. Components of Centrifugal Switch

WINDINGS. The split-phase motor has two windings. One winding is of heavy insulated copper wire, which is generally located at the bottom of slots in the starter and are called "Run Windings" or "Main Windings." The other winding is called the "Start Winding" and is generally located in the starter on top of the run winding. The start winding and the run winding are connected to power until the motor reaches 75 percent of its maximum RPM. The centrifugal switch disconnects the start winding from the power. The run winding is made up of many turns of heavy copper wire and the start winding is made up of fewer turns of small wire. If the start winding is not disconnected after a short period of time, it will burn up.

CENTRIFUGAL SWITCH. The rotating part of a centrifugal switch is a mechanical mechanism that relies on motion and flyweights to operate. As the rotor turns the flyweights are pulled out by centrifugal force. This applies pressure to the closed contacts of the switch causing them to open. These contacts are in series with the start winding. The opening of the contacts will deenergize the start-winding, see figure 73.

OPERATION. When a split-phase motor is started, current flows through both the running and the starting winding. This causes a magnetic field to be formed inside the motor. The magnetic field induces a current in the rotor windings, which, in turn, causes a magnetic field in the rotor. The magnetic fields combine in such a manner as to cause rotation of the rotor. The start winding is necessary at the start in order to produce the rotating field effect. After the motor is running, the start winding is no longer needed and is cut out of the circuit by means of the centrifugal switch. After the start windings are cut out, the motor operates on a shifting magnetic field.

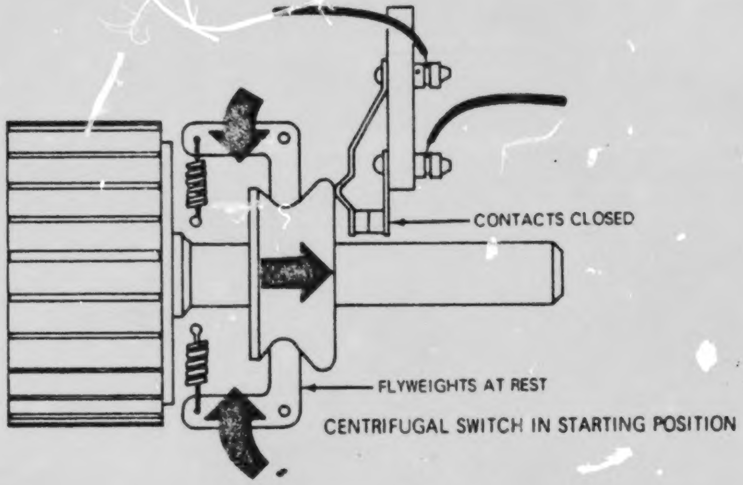
Capacitor Motors

Capacitor motors are made in sizes ranging from 1/20 to 10 horsepower. They are widely used to operate refrigerators, washing machines, air compressore, air conditioners, and fans.

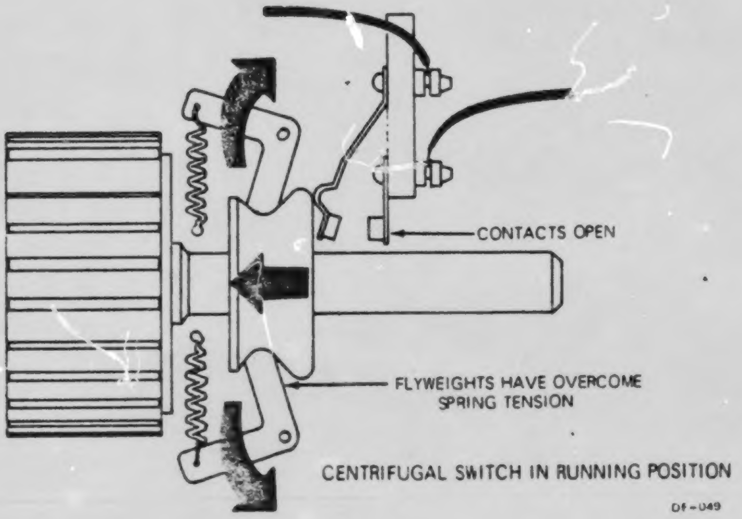
A capacitor motor is constructed similarly to a split-phase motor. A capacitor has been added to give the motor better starting torque.

CAPACITOR-START MOTOR. A capacitor-start motor is an improved version of the basic split-phase type motor. An intermittent type of capacitor is connected in series with the start winding. When the motor reaches 75 percent of full speed, the centrifugal switch cuts out the start windings and the capacitor. The capacitor added in the start windings gives the motor a greater starting torque than a basic split-phase motor.

To create a starting torque in a capacitor motor, a better rotating magnetic field has to be established inside the motor. This is accomplished by placing the starting winding out of phase with the running windings by more electrical degrees. A capacitor is used to cause the current in the start winding to reach its maximum value before the current in the running winding becomes maximum. Actually, the capacitor causes the current in the start winding to lead the current in the running winding. This causes a revolving magnetic field in the stator which induces a current in the rotor and causes it to rotate.



CENTRIFUGAL SWITCH IN STARTING POSITION



CENTRIFUGAL SWITCH IN RUNNING POSITION

Figure 73

PERMANENT-SPLIT CAPACITOR MOTOR. The permanent-split capacitor consists of a standard split-phase type stator, a squirrel-cage rotor, a capacitor and endbells. This is another version of the basic split-phase motor. A permanent type capacitor is connected in series with the starting windings and left in the circuit at all times. The starting windings in this motor are not a high resistance winding and have the same number of turns and wire size as the run windings. The capacitor is used instead of resistance to give the split-phase effect. This eliminates the need for a centrifugal switch in this motor. The capacitor is continuously rated and is selected to give best operation at full speed while sacrificing starting torque. The permanent-split capacitor motor has the operating characteristics of poor starting torque with a high current draw, but runs with a good torque under load, at a constant speed.

Commutator Motors

Single-phase commutator motors have a drum-wound armature, commutator, and brushes. This study guide will cover the simple repulsion, repulsion start-induction run, repulsion induction, and universal.

SIMPLE REPULSION MOTOR. The simple repulsion motor consists of a single concentric type stator, a wound rotor, a commutator, two carbon brushes, compensating windings, and endbells. The stator windings and the compensating windings are connected in series. The compensating windings are used to improve the power factor in this motor. Two carbon brushes are employed on the commutator. The two brushes are short-circuited to each other. This motor has the operating characteristics of high starting torque and low starting current draw. Although its starting torque is useful, its large variation of speed with load is not desirable in many applications. This motor is commonly made in sizes from 1 to 10 horsepower and is used to power such loads as conveyors, small compressors, and woodworking equipment. The simple repulsion motor is shown in figure 74.

REPULSION START-INDUCTION RUN MOTOR. The repulsion start-induction run motor consists of a single concentric type stator, a wound rotor, compensating windings, a centrifugal device, and endbells. This type of repulsion motor uses four carbon brushes: two are short-circuited together, the other two brushes are connected in series with the compensating winding. The compensating windings in this motor are used to improve the power factor during the starting period. The centrifugal device used in this motor consists of a shorting ring and a brush lifting mechanism. As the motor reaches approximately 75 percent of its rated speed, the centrifugal device forces the short-circuiting ring into contact with the inner surface of the commutator segments and converts the motor into an induction motor. At the same time, the centrifugal mechanism raises the brushes, which reduces wear of the brushes and commutator. This motor has the operating characteristics of high starting torque with a low current draw and a constant running speed under load. The repulsion start-induction run motor, shown in figure 75 is made in sizes from 1/4 to 10 horsepower and is used to power such loads as compressors, fans, pumps, stokers, and farm machinery.

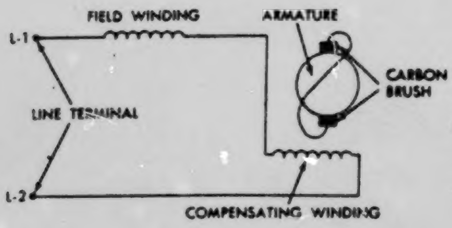

FIELD WINDING
ARMATURE
L-1
CARBON BRUSH
LINE TERMINAL
L-2
COMPENSATING WINDING

Figure 74. Schematic Wiring Diagram of a Single-Phase Repulsion Motor

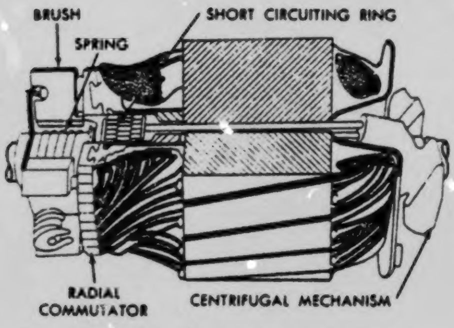

BRUSH
SPRING
SHORT CIRCUITING RING
RADIAL COMMUTATOR
CENTRIFUGAL MECHANISM

Figure 75. Repulsion-Start Induction-Run Motor Rotor

REPULSION-INDUCTION MOTOR. The repulsion-induction motor consists of a single concentric type stator, a combination rotor, a commutator, brushes, compensating windings and endbells. This type of motor has four carbon brushes, two being short-circuited together; the other two brushes are in series with the compensating windings. The compensating windings in this motor are used to improve the power factor of the motor and to reduce some of the sparking at the brushes. This motor does not have a centrifugal switch or device but instead has a squirrel-cage winding on its rotor in addition to a wound rotor. Rotors of this type are called combination rotors. The squirrel-cage winding is placed underneath the wound rotor section and is so constructed as to have high-inductive reactance. At low speeds, very little current flows in the squirrel-cage windings and the motor starts as a repulsion motor. When the motor reaches operating speed, the frequency of the induced rotor currents is low, so that current flows more in the squirrel-cage winding and the motor operates as an induction motor. This motor has the operating characteristics of high starting torque with a low current draw and a constant running speed under load. The major disadvantage of this motor is that the brushes remain on the commutator, causing arcing, thus increased maintenance. The repulsion-induction motor shown in figure 76 is made in sizes up to 10 horsepower and is used to power such loads as printing presses, textile machines, and laundry extractors. To reverse the direction of rotation the brushes must be shifted past the neutral plane.

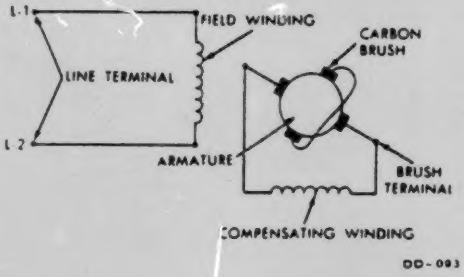

L-1
FIELD WINDING
CARBON BRUSH
LINE TERMINAL
L-2
ARMATURE
BRUSH TERMINAL
COMPENSATING WINDING
DD-093

Figure 76. Schematic Wiring Diagram of a Single-Phase Repulsion-Induction Motor

Universal Motor

A universal motor is one that can operate on either single-phase alternating current or direct current. These motors are normally made in sizes ranging from 1/200 to 3/4 horsepower. They are obtainable in much larger sizes for special conditions. The fractional horsepower sizes are used on vacuum cleaners, sewing machines, food mixers, and power handtools. There are several types of universal motors; however, the salient pole type is more popular than the other types.

The salient pole type consists of a stator with two concentrated field windings, a wound rotor, a commutator, and brushes. The stator and rotor windings in this motor are connected in series with the power source. Two carbon brushes are employed in this motor and remain on the commutator at all times. These two brushes are used to connect the rotor windings in series with the field windings and the power source, see figure 77.

The universal motor does not operate at a constant speed. The motor runs as fast as the load permits--low speed with a heavy load and high speed with a light load. Universal motors have the highest horsepower to weight ratio of all of the types of electric motors.

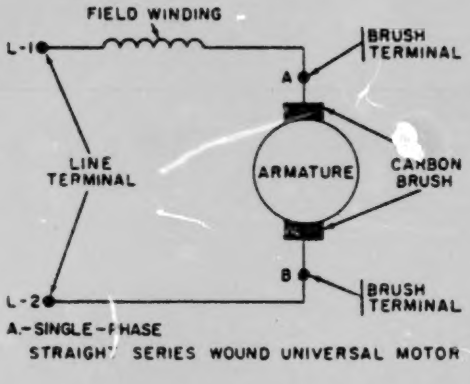

FIELD WINDING
L-1
BRUSH TERMINAL
A
LINE TERMINAL
ARMATURE
CARBON BRUSH
B
L-2
BRUSH TERMINAL
A.-SINGLE-PHASE STRAIGHT SERIES WOUND UNIVERSAL MOTOR

Figure 77. Universal Motor

SINGLE-PHASE MOTOR CONNECTIONS

Split-phase and capacitor start motors are made for either single or dual voltage operation. The single voltage, nonreversible type will have only two leads--1 and 2. The single voltage reversible motor will have four leads numbered 1, 2, 5, and 8. A dual voltage nonreversible motor will have four leads numbered 1, 2, 3, and 4. The dual voltage reversible motor leads will be numbered 1, 2, 3, 4, 5, and 8. Leads numbered 6 and 7 are terminals of coils which are connected internally.

In order to operate a dual voltage motor on the high voltage, the running winding must be connected in series as shown in figure 78. Leads 2, 3, and 8 are connected and taped, leads 1 and 5 connect together and go to power. Lead 4 goes to power, see figure 78.

To operate on the lower voltage, the running windings are connected in parallel. Leads 1, 3, and 5 are connected together, then to power. Leads 2, 4, and 8 connect together, then to ground, see figure 79.

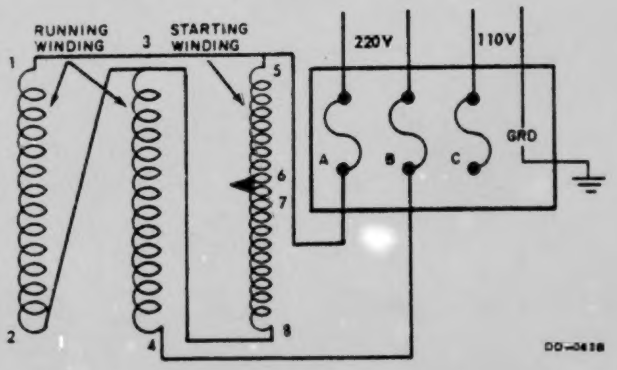

RUNNING WINDING
3
STARTING WINDING
1
5
6
7
2
4
8
220V
110V
A
B
C
GRD

Figure 78. Schematic of Single-Phase Motor Windings Connected for High Voltage--220 Volts

The starting winding is always connected in parallel with the running winding, regardless of which voltage (high or low) is connected to the motor. The starting winding cannot at any time have more than 120 volts across it.

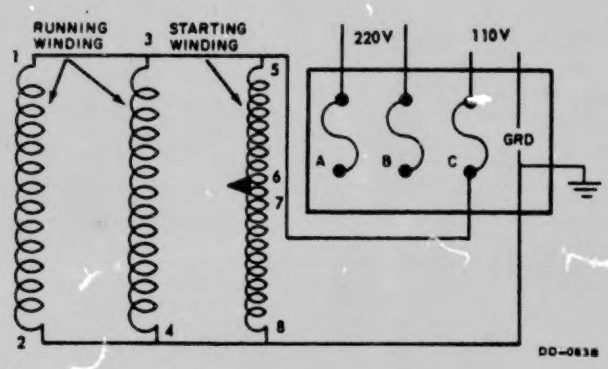

RUNNING WINDING
STARTING WINDING
220V
110V
GRD
A
B
C
1
2
3
4
5
6
7
8
DD-0838

Figure 79. Schematic of Single-Phase Motor Windings Connected for Low Voltage--110 Volts

To reverse direction of rotation of a single-phase induction motor, the start winding leads must be interchanged. Leads 5 and 8 are the start winding leads. High voltage would be leads 2, 3, and 5 connected together and taped. Leads 1 and 8 are connected together, then to power, and lead 4 connects to power. Figure 80 shows these connections. The same method is used for low voltage. Leads 1, 3, and 8 connect to power and 2, 4, and 5 to ground.

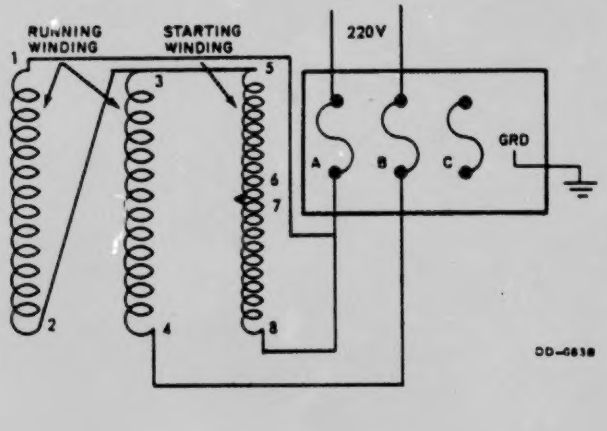

RUNNING WINDING
STARTING WINDING
220V
GRD
A
B
C
1
2
3
4
5
6
7
8
DD-0838

Figure 80. Reversing Direction of Rotation of a Single-Phase Motor Connected for High Voltage

Motors chosen for a specific task must be properly rated, constructed, and protected for their work. Such factors as size, type of voltage, enclosure, speed, mounting requirements, direction of rotation, torque, types of bearings, shaft size, and temperature must be considered.

When selecting a motor for a specific function, one of the first things to consider is the available power. The power supply must have the required phases and voltage to run the size motor needed to drive the load.

Motors are classified according to size, as either being fractional horsepower or integral housepower. A fractional horsepower motor is any motor rated less than one horsepower, while an integral horsepower motor is rated at one horsepower or larger. This classification is made by the National Electric Manufacturer's Association (NEMA).

Motors are also classed by construction or enclosure according to mechanical protection afforded or the method used for cooling.

Common types of enclosure are as follows:

- Open Motor - An open motor has ventilating openings in the frame which permit the passage of cooling outside air over and around the windings.
- Splashproof - A splashproof motor is an open motor in which the vent slots are made to prevent liquids or solids from entering them except at indirect angles.
- Totally Enclosed - This motor is built to prevent free passage of outside air. It is not airtight; therefore, it cannot be used in an explosive area.
- Drip Proof - A drip-proof motor is an open motor in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine, either directly or by striking and running along a horizontal surface, will not enter the motor.
- Waterproof Motor - A waterproof motor is a totally enclosed motor so constructed that it will exclude water applied in the form of a stream from a hose.
- Explosionproof - Explosionproof motors are designed to withstand an internal explosion of the vapors or dust from the area in which they are used and to prevent an explosion due to motor faults.

Location of installation will determine the type of enclosure of the motor. For example, an open motor would be used where the motor is protected from the elements by its surroundings. Totally enclosed motors would be used where there is a need to restrict the passage of outside air. Explosionproof motors are used where a hazardous condition exists or might exist. According to Article 500 of the N.E.C., hazardous locations are classed into three categories:

Class I - Locations containing flammable gasses or vapors.

Class II - Locations containing combustible dust.

Class III - Locations containing easily ignitable fibers or filings.

Article 500 of the N.E.C. also breaks down hazardous conditions into two divisions:

Division I - The hazardous condition is normally present.

Division II - The hazardous condition is not normally present but may occur.

Along with enclosures the location of the motor will also determine the temperature of the motor. Normal temperature rise of a motor is 40°C. This rise is added to the ambient (surrounding) temperature of the motor

Duty of a motor is defined as the frequency in which it is started. This is an important factor in motor selection since motor windings heat rapidly during starting. For our purposes, we will divide motors into continuous duty and intermittent duty categories. Along with duty comes the term service factor. Since some motors are classed as general-purpose motors, they may have a service factor stamped on the data plate. The normal horsepower rating is multiplied by the service factor to give the safe overload capacity of the motor. For example, a five-horsepower motor with a service factor of 1.15 can be used to carry a continuous load of 5.75 hp (5 X 1.15). Normal service factor is 1.15.

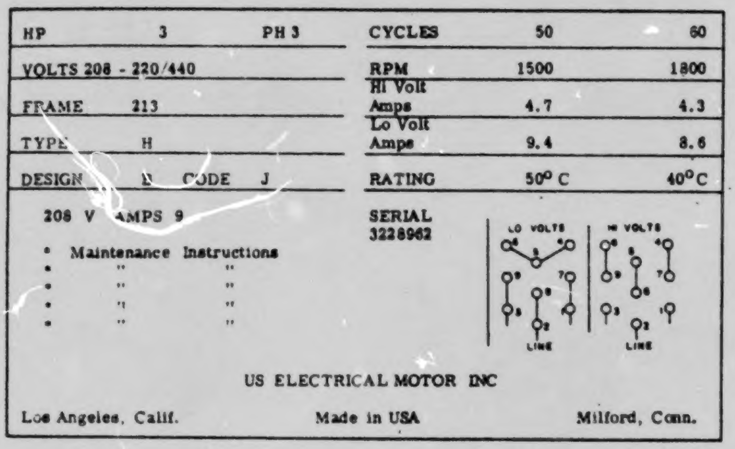
The types of bearings used in a motor usually depend on their application to a load or on its mounting plane, whether horizontal or vertical. As a general rule, sleeve bearing motors are horizontal mounted and ball or roller bearing motors are designed for vertical or horizontal mounting. The speed of the motor and size of the shaft are determined by the equipment to be driven or the load to be applied to the motor shaft. The connection to the shaft is made in different ways depending on the load. Keyway and key, pulley, couplings, and gears are common methods for connecting the shaft to the load.

According to the Article 430-7 in the N.E.C., motors shall be marked with certain information, such as the following:

1. Manufacturer's name.
2. Rated volts and full-load amps.
3. Rated frequency and number of phases.
4. Rated full-load speed.
5. Rated temperature rise.
6. Time rating
7. Rated horsepower if 1/8 or more

97

Along with required information, manufacturers volunteer useful information, such as frame number, type, design, serial number, and motor connection, see figure 81.



HP	3	PH 3	CYCLES	50	60
VOLTS 208 - 220/440			RPM	1500	1800
FRAME	213		Hi Volt Amps	4.7	4.3
TYPE	H		Lo Volt Amps	9.4	8.6
DESIGN	B	CODE J	RATING	50° C	40° C

208 V AMPS 9

SERIAL 3228962

- Maintenance Instructions
- " "
- " "
- " "
- " "

US ELECTRICAL MOTOR INC

Los Angeles, Calif. Made in USA Milford, Conn.

DO-092

Figure 81. Motor Data Plate

Summary

The stator of a three-phase motor is constructed with semiclosed slots for windings which are connected either in a wye or in a delta fashion.

The kind of rotor used in a three-phase stator actually determines the kind of the three-phase motor. There are two distinct types of rotors: (1) the squirrel-cage, and (2) the wound rotor. The squirrel-cage is the simplest in construction and requires less maintenance than the other types: therefore, it is the most popular. The three-phase motor operates on the theory of a rotating magnetic field established in the stator. Slip is the time difference between the rotating magnetic field and the rotor. Stall point is 25 percent slip and locks the rotor stationary. To figure amount of slip synchronous speed must be known. The formula for synchronous speed is $\text{RPM} = \frac{\text{frequency X 120}}{\text{number of poles}}$

With synchronous speed known, percent of slip is figured with the following formula:

$\text{Slip} = \frac{ss - rs}{ss} \times 100.$ The windings of three-phase motors are brought out from the stator to an external power source. The windings are connected for either wye or delta operation, 220-volt or 440-volt power supply. To reverse the direction of rotation of a three-phase motor, two power leads must be interchanged.

To develop skill and proficiency in the connecting, operating, and maintaining single-phase motors, you should know as much about them as possible.

12

The various types of single-phase motors are capacitor start, split-phase, universal motors, and repulsion motors. All of these motors operate on the principle of interaction between magnetic fields. The major difference between single-phase motors is usually in the method used for starting. Capacitor start motors, of course, employ the use of a capacitor to throw the starting current out of phase with the running current. This acts to shift the magnetic fields acting on the motor rotor to provide starting torque. Universal motors have a wound rotor the same as a direct current motor but they are designed to operate both on ac and dc. Split-phase motors have a separate starting winding which serves to affect the necessary phase shift for starting.

To select the proper motor to do a job, many factors have to be considered. Among these are the type of power supply, amount of horsepower required, speed, and direction of rotation.

The environment the motor must operate in will determine the type of housing used to protect the motor, also the position a motor is mounted in will determine what type of bearings are needed.

The motor data plate furnishes much valuable information, such as hp, volt, amp, and service factor.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.
2. Textbook; Basic Electricity/Electronics. Van Valkenburgh, Nooger, and Neville.

CAPACITORS

A capacitor is sometimes called a condenser. You probably have seen many capacitors or condensers in places other than on a motor, such as automobile distributors, radios, and TV sets. A capacitor may be called a device to store a quantity of electrons.

In making a capacitor, all that is necessary are two or more metallic plates separated by air or an insulating material. This insulation between the plates is termed the "dielectric." You could take two sheets of metal and place a newspaper between them and you have made a capacitor.

Capacitors are named for the dielectric material used. The two major types are the electrolytic or start capacitor and the oil paper or run capacitor. Electrolytic capacitors consist of strips of aluminum foil rolled together. The dielectric is chemically produced to give the effect of two plates and a dielectric. The running capacitor consists of two sheets of foil separated by a heavy oil paper dielectric and rolled together.

The capacitance of a capacitor is rated in Farads. For practical purposes the farad is too large a unit of measurement, so the term "Microfarad" or one millionth of a farad is used (mfd).

The features that determine how much capacitance a capacitor will have are the area of the plates, the larger the area, the more capacitance, and the dielectric constant of the insulation between the plates. Other things being equal the capacitance is directly proportional to the area of the plates. If we double the plate area, we double the capacitance.

Capacitors come in various sizes and capacities. No specialist can be expected to have an exact replacement for each defective capacitor he may encounter. Many substitutions can be used. When making these substitutions a few rules to remember can keep you out of trouble. They are as follows:

1. The voltage rating of any replacement capacitor MUST be equal to, or greater than, the capacitor being replaced.
2. When replacing a start capacitor, the mfd must be equal to, but no greater than 20 percent more than that of the capacitor being replaced.
3. When replacing a run or P.S.C. capacitor, the mfd rating must vary no more than ± 10 percent of the rating of the capacitor being replaced.
4. DO NOT GO BEYOND THESE LIMITATIONS WITHOUT EXPLICIT INSTRUCTIONS FROM THE MOTOR MANUFACTURER.

It is sometimes necessary when substituting capacitors to use two or more capacitors to replace one capacitor. These multiple capacitors must be wired correctly or the motor will not operate properly. Never use starting and running capacitors together.

When wiring capacitors in parallel the rules are simple.

1. All capacitors must have a voltage rating equal to, or greater than the replacement capacitor.

2. The total mfd rating is the sum of the mfd rating of each capacitor. For example you wanted to replace a 160 mfd capacitor rated at 440 volts and you had five capacitors to choose from:

1.	2.	3.	4.	5.
60 mfd 220 Volts	100 mfd 330 Volts	40 mfd 440 Volts	120 mfd 440 Volts	100 mfd 440 Volts

Capacitors 1 and 2 would be eliminated as the voltage ratings are not equal to the original.

Numbers 3, 4, and 5 meet the voltage requirement but only 3 and 4 add up to the proper mfd rating. In this case 3 and 4 would be our substitutions.

When connecting capacitors in series the arithmetic is a little more difficult. The rules are:

1. The sum of the voltages must equal the voltage of the replacement.

2. Total capacitance of capacitors in series is found by the following formula.

$$C = \frac{C1 \text{ X } C2}{C1 + C2} = \text{mfd}$$

For example if you should need a mfd rating of 20 and you had two 40's available, the formula would be:

$$C = \frac{40 \text{ X } 40}{40 + 40} = \frac{1600}{80} = 20 \text{ mfd}$$

If a capacitor-start motor fails to operate, it may be the capacitor which is at fault. To check a capacitor to determine its condition, you must first discharge it. This discharging is accomplished by crossing (shorting) the two terminal leads together. CAUTION: Do not touch the bare portion of the capacitor leads. It is advisable to always discharge a capacitor with a resistor in series with the terminals. This prevents any large surge of current that could damage the capacitor and injure you. After discharging the capacitor, remove it from the unit. Obtain an ohmmeter and set it on Rx 100 scale. Place the test leads on the capacitor terminals. If the capacitor is good, the needle will move to an ohm reading and then move slowly back to infinity. If the meter reads zero ohms, the capacitor is grounded or shorted and if the meter reads infinity, the capacitor has an open and must be replaced, see figure 82.

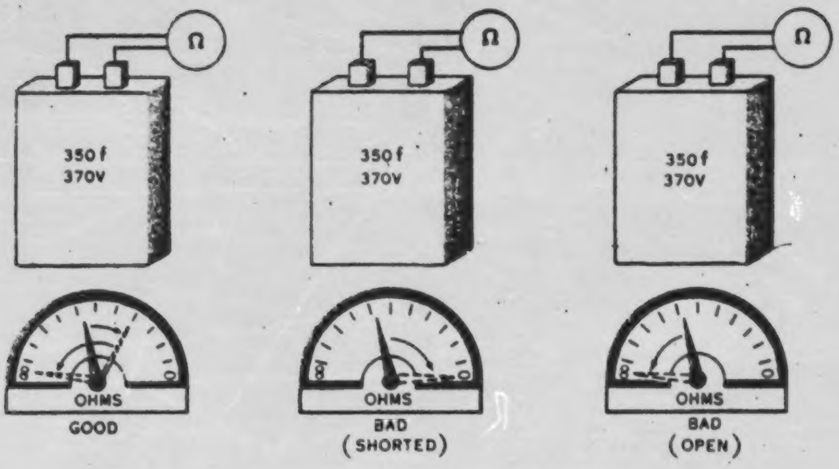

Ω
350f
370V
∞
0
OHMS
GOOD
BAD
(SHORTED)
BAD
(OPEN)

Figure 82.

All capacitors should have ratings stamped or painted on them. Occasionally these readings become unreadable. Also on some troublesome service calls it becomes necessary to check capacitor ratings. This check can be accomplished quickly and simply with the following equipment:

1. Standard light cord and two alligator clips.
2. Fuse receptacle.
3. Voltmeter.
4. Ammeter.

The wiring diagram in figure 83 shows how the meters are wired into the circuit.

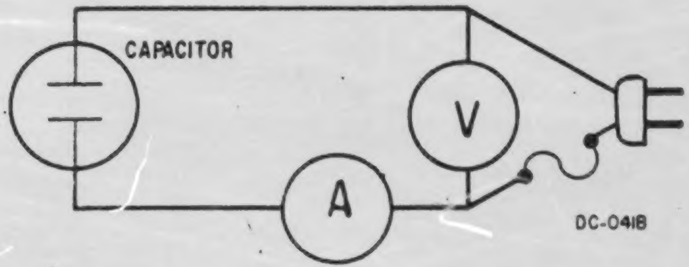

CAPACITOR
V
A
DC-0418

Figure 83.

The capacitor is discharged and the alligator clips attached to it, the voltmeter is placed across the line and the ammeter and fuse are in one side of the line.

The test cord is inserted to voltage and the meter readings quickly taken. The plug is removed and the mfd rating is determined by the following formula:

$$\text{mfd} = \frac{2650 \text{ X AMPS}}{\text{Volts}}$$

Suppose for example our voltmeter indicated 100 Volts and the ammeter indicated 10 amps using our formulas we can determine the mfd rating of the capacitor tested.

$$\text{mfd} = \frac{2650 \text{ X } 10}{100} = 265 \text{ mfd}$$

An important thing to remember is that the fuse is there to protect the ammeter and you. Never bypass or eliminate it. If the ammeter scale to be used is peaked at 50 amps, the fuse must be less than this anticipated high.

Summary

The purposes of capacitors are to provide starting torque for motors, improve their running characteristics and efficiency, and improve the power factor. Selection and testing capacitors is an important part of your job. Knowing the rules of selection and the procedures for testing these units will aid you in accomplishing your duties as a refrigeration specialist.

References:

Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

SG 3AZR54550-2-I-3
May 1974

THERMODYNAMICS, PRINCIPLES OF REFRIGERATION

OBJECTIVES

This unit of study is designed to develop a sound knowledge of the definition of terms, and fundamental principles of the mechanical refrigeration cycle. It provides the foundation upon which a thorough knowledge of refrigeration and air conditioning is based.

INTRODUCTION

In order to be a proficient and competent specialist, you must have knowledge of the terms applied, and the physical and chemical processes of refrigeration. It is important that you become thoroughly familiar with the principle and operation of the refrigeration cycle.

STUDY ASSIGNMENT: Modern Refrigeration and Air Conditioning, paragraphs 1-1 through 1-53.

STUDY NOTES

Paragraph 1-3.

A schematic drawing of a simple compression type refrigeration mechanism is shown in figure 84. Follow the flow of refrigerant, beginning with the liquid receiver, through the liquid line, up to the refrigerant control and into the evaporator. In the evaporator, the pressure is reduced and the refrigerant boils at a low temperature and absorbs heat from the surrounding space. The refrigerant is now a vapor and is drawn down the suction line to the compressor where it is again compressed to a high temperature and pressure and pushed into the condenser where it readily gives up its absorbed heat and returns to a liquid.

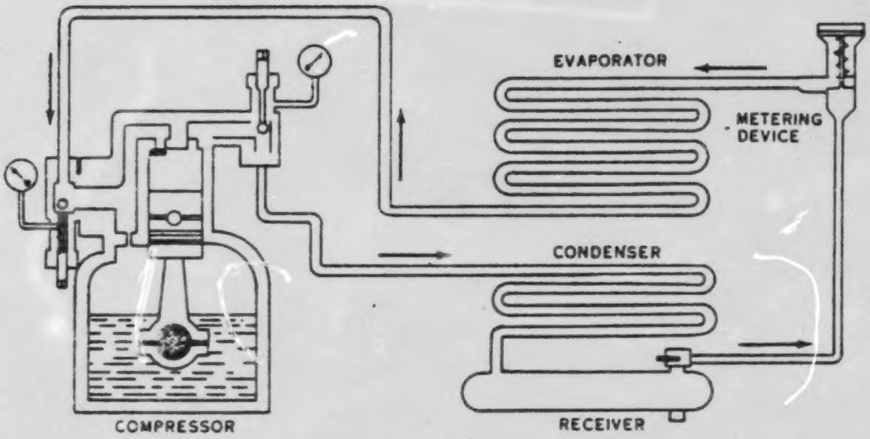


Figure 84.

Again referring to figure 84, we will review the above.

1. Liquid receiver - Liquid refrigerant is stored here
2. Refrigerant control - Maintains the pressure difference between the high and low sides of the system
3. Evaporator - The liquid refrigerant boils and absorbs heat from the surrounding space
4. Compressor - The vaporized refrigerant is drawn into the compressor and is compressed to a high pressure and temperature and is pumped to the condenser
5. Condenser - The high-pressure, high-temperature vapor gives up the heat that was absorbed in the evaporator. The refrigerant returns to a liquid and flows to the receiver ready to repeat the cycle

Paragraphs 1-4, 5, and 6

Molecular motion increases with temperature. To cool a substance means to slow down its molecular motion. Heat always flows from hot to cold. In order to transfer heat, you must arrange the conditions so that the temperature of the substance receiving heat is colder than the substance releasing heat.

Heat is a form of energy. Temperature is an indication of the speed of the molecule motion. The motion of the molecules of a substance at a high temperature is faster than the motion of the molecules of a substance at low temperature.

The amount of heat in a substance depends upon three factors.

1. Its temperature
2. The amount of the substance (weight)
3. The material of the substance (specific heat)

Paragraphs 1-7, 8, 9, and 10

Thermometers are used to measure temperature. There are several thermometer scales, the most common being Fahrenheit and centigrade. Comparison of these scales is shown in figure 1-3 of the textbook. Note that the illustration shows water freezing at "0" degrees centigrade and "32" degrees Fahrenheit and boiling at "100" degrees centigrade and "212" degrees Fahrenheit. These are actually the same temperatures, but on different scales.

With the development of cryogenic substances and temperatures, absolute temperatures are sometimes used. The Rankine (R) is the Fahrenheit absolute scale and the Kelvin (K) is the absolute centigrade scale. With these thermometers it is never necessary to deal with minus temperatures. Careful study of paragraph 1-8 will help you in understanding practical use of these scales.

The absolute zero on the Rankine and Kelvin scales is considered the temperature at which there is no molecular movement.

Paragraphs 1-13, 14, and 15

Most substances exist in three common states: solid, liquid, and gas. Use water as an example at atmospheric pressure. If frozen it is ice, a solid. If heated to a temperature of 32 degrees F or above it will be water, a liquid. If heated above 212 degrees F it will be steam, a vapor or gas.

A solid maintains a certain shape.

A liquid conforms to the shape of its container.

A gas or vapor must be confined in a container or it will escape or dissipate.

Paragraphs 1-16, 17, 18, and 19

Pressures are a very important factor in refrigeration systems. The fact that a substance is a solid, liquid or gas is dependent upon both the pressure and the temperature of the substance. In figure 84 the pressure in the evaporator was reduced, consequently the refrigerant boiled at a low termperature.

Paragraphs 1-23, 24, 25, 26, 27, and 28

Temperature of a substance may be measured with a thermometer, however there is no instrument that may be used to measure the amount of heat in any substance. The amount of heat must be calculated. The unit of heat is the British thermal unit (Btu). This is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

As heat is added to a substance and its temperature increases, the increase is known as sensible heat. Sensible heat can be felt by touch and measured with a thermometer. Further defined, sensible heat causes a change in temperature but not state.

The amount of heat required to change the temperature of a substance one degree Fahrenheit is termed specific heat.

Latent heat of a substance can neither be felt or measured with a thermometer. It is the heat required to change the state with no change in temperature. Figure 1-16 shows the effects of sensible and latent heat with water as a standard.

Paragraphs 1-29, 30, and 31

A ton of refrigeration effect is the amount of heat required to melt one ton of ice per 24 hours. One pound of ice in melting will absorb 144 Btus. Dividing 288,000 by 24 equals 12,000 Btu/hr.

Paragraphs 1-34, 35, and 36

One horsepower is equal to 2,545.6 Btu/hr. This is equal to 746 watts of electrical energy; 778 foot-pounds equal one Btu. In many refrigeration calculations, it is necessary to convert the value of one form of energy into equal values of another form of energy.

Figure 1-19 should be studied carefully. It will show you the effect of pressure, temperature, and latent heat of vaporization on the behavior of a liquid refrigerant under pressures.

Paragraphs 1-37, 38, 39, 40, and 41

Heat may be transferred from one place to another by three methods: conduction, convection, and radiation. You learned that heat always flows from hot to cold. It is well to read carefully the paragraphs of heat transfer methods.

Paragraphs 1-50, 51, 52, and 53

The gas laws frequently referred to in refrigeration work are Boyle's Law, Charle's Law, Gas Law, and Dalton's Law. Careful study of the problems and solutions in the above paragraphs is important to understanding these processes.

SUMMARY

Refrigeration, the transfer of heat from a place where it is not wanted, is almost as old as history. The growth of mechanical refrigeration in the past few years has been greater than all the previous years combined.

Heat is a form of energy. It affects all substances around us, causing them to be in one of three physical states, depending on temperature: solid, liquid, or gas. Heat in the summertime is uncomfortable where people gather. Heat causes food to spoil and medicine to deteriorate.

Heat flows from hot to cold by three methods: conduction, convection, and radiation. Its intensity is measured in degrees of temperature, while its quantity is measured in Btus.

A refrigeration system depends directly on a difference in pressure for its basic principle of operation. Pressure affects the boiling point of a liquid refrigerant and the condensing point of a gas.

A compression refrigeration system has four major component parts: compressor, condenser, refrigerant control, and evaporator. The fluid circulated inside the system is called the refrigerant. It is this fluid that carries the heat in the refrigeration cycle.

References:

Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano

HEAT LOAD ESTIMATION

STUDY ASSIGNMENT: Modern Refrigeration and Air Conditioning, paragraphs 16-1 through 16-30

STUDY NOTES

Paragraph 16-1

The first step in figuring the size of a refrigeration machine is to calculate the amount of heat the evaporator and condensing unit must remove. Using this information you can make a selection from the manufacturer's literature to suit your need.

Paragraph 16-2, 3

You have previously learned that heat travels by conduction, convection, and radiation, or a combination of these methods. In this unit, you will learn how these methods affect the refrigerating load. You must understand the basic principle of heat conduction and the various ways that have been developed to figure the amount of heat that flows through the walls of a container.

Paragraphs 16-4, 5, 6, and 7

You should readily understand that the air that finds its way into the cabinet must be cooled. Heat from light, motors, and product must be removed. All the sources of heat except heat leakage are added together and are called the service or heat usage load.

Paragraphs 16-8, 9, and 10

The instructions for balancing the heat removing capacities of the evaporator and condensing unit are very important. Read this material several times! From it you can see why a system designed for use in high temperature cabinets will not work in low temperature applications.

Paragraphs 16-13, 14, 15, and 16

Evaporator capacity must match the condensing unit capacity. They must be installed correctly to insure that this capacity is not decreased.

Paragraphs 16-17, 18, 19, 20, 21, 22, 23, and 24

The calculations of evaporator area instruction applies to coils designed to cool air. You should do the arithmetic for each.

Paragraph 16-25

Forced convection evaporators use motor-driven fans or blowers. Their heat removing capacity varies greatly. You should always consult the manufacturer's specifications when installing or replacing a unit.

Paragraph 16-26, 27, 28, and 29

Because the heat transfer rate of a liquid is very high, liquid or beverage coolers are usually very compact. The heat usage of ice cream is quite low because of the previous freezing of ice cream.

Paragraph 16-30

If a condensing unit is too small, it will run all the time with poor refrigeration effect. If it is too large, it will be uneconomical and may short cycle.

SUPPLEMENTARY INFORMATION

HEAT LOAD ESTIMATION

Equipment Sizing

On large refrigeration installation, a great deal of complicated calculations are necessary to determine the correct type and size of equipment. This problem is handled by the refrigeration engineer. It is not our objective to teach you to be engineers. However, you do need to know enough about the procedures and terms used to be able to talk with the engineer concerning size, type, and application of equipment.

The heat load and temperature range must be considered when selecting refrigeration equipment. A one-ton unit cannot handle a five-ton load. Neither will a unit rated to handle one ton at 32°F be able to handle that load at 0°F.

CALCULATIONS. To calculate the total heat load, we will use a walk-in box as an example. The following heat sources must be considered:

Wall heat gain
Air content load
Product load
Miscellaneous (heat from lights, motors, etc)

To reduce the chance of error, each heat source should be calculated separately and then added together to get the total heat load.

Load Estimate Sheet. The first step in selecting refrigeration equipment is to get the following design information and make up a problem sheet.

Reference Tables. These tables are included in this book (pages 84 through 92). They list ambient temperature conditions, as well as product storage information, used in heat load estimating.

Outside Ambient Temperature. The weather bureau has published charts giving the design ambient temperature for most cities of the United States. A partial list of these cities is listed in Table 1.

Outside Dimensions. Use a steel tape to measure the box.

Insulation. Check the type and thickness of the insulation. Get the overall wall thickness. If the wall covering is metal, then the overall thickness and insulation thickness are the same. If the wall covering is wood, then subtract two inches from the overall wall thickness for the insulation thickness.

Product Load. The amount of product to be placed in the box and its entering temperature should be known. You must also know whether the product is to be frozen and removed every 24 hours or stored for short or long times. This information is needed to calculate the amount of heat the product will give off in 24 hours.

Miscellaneous Load. This includes electric lights, motors, and people. When making your list of miscellaneous items make sure to get the correct horsepower of the motors, the number of lights, their wattage and burning time, the number of people and the length of time they spend in the refrigerated space.

In figure 85, a load estimate form is filled in using this problem and the following steps.

Sixteen hundred and fifty pounds of lettuce arrived at Sheppard Air Force Base for short time storage. The lettuce arrived in a refrigerated truck at 55°F. There is a 100-watt bulb that burns two hours per day. A 1/8-horsepower evaporator fan motor runs continuously. The relative humidity is 50 percent.

Step 1. Fill in the "application" blank. The product to be stored is lettuce.

Step 2. For outside ambient temperature, go to Table 1 and look for Texas. Select the city nearest Wichita Falls. Get the dry bulb temperature of 100°F.

Step 3. Go to Table 2. Find lettuce in the product column. Go across to get the short storage temperature for the room temperature blank which is 45°F.

Step 4. To get temperature difference subtract the room temperature from the outside ambient temperature. The TD is 55°F.

Step 5. Place the room dimensions in their proper places. L = 8 feet, W = 6 feet, and H = 8 feet.

Step 6. Write in the insulation type, which is Fiberglas three-inches thick.

Step 7. The overall wall thickness is three inches.

Step 8. Amount of Product--1650 pounds of lettuce entering at 55°F.

Step 9. Fill in the miscellaneous loads--number of people, none; total wattage of lights, 100 burning two hours; motor size, 1/8 horsepower operating 24 hours.

Step 10. Determine the number of square feet of surface area by using this formula: Area = 320 square feet.

L X W = ?	8 X 6 = 48
L X H = ?	8 X 8 = 64
H X W = ?	6 X 8 = 48
Total = ?	Total = 160
X 2	X 2
?	320 square feet

Step 11. Determine the number of cubic feet of inside volume by using this formula: L X W X H = Cubic Feet. If outside dimensions are used then double the wall thickness and subtract it from each dimension, then multiply one dimension times the other. The overall wall thickness is three inches. Three inches times two = six inches.

L = 8 feet - 6 inches = 7.5 feet

W = 6 feet - 6 inches - 5.5 feet

H = 8 feet - 6 inches = 7.5 feet

$$\begin{array}{r} 7.5 \text{ feet} \\ \underline{5.5 \text{ feet}} \\ 37.5 \\ \underline{375} \\ 41.25 \\ \underline{7.5} \\ 20625 \\ \underline{28875} \\ 309375 \end{array}$$

The decimal is pointed out in the final number 309.375

If the first number to the right of the decimal is five or greater, then increase the first number to the left of the decimal by one and drop the fraction. If the first number to the right of the decimal is less than five, drop the fraction without any increase. Volume = 309 cubic feet

Step 12. To get the wall load write in the area from step 10. Now go to Table 3. Look in the insulation thickness column for three inches. Go across to the temperature difference of 55°F from step 5 and get 132. Multiply 132 times 320 to get the total 24-hour heat load of 42240 Btu.

Step 13. Air Change Load. Write in the volume from step 11. Since the room temperature is above 32°F use Table 4B. Look under Volume Cubic Feet for the number nearest your volume number. Go to its left and get the air changes of 34.5. Use Table 5 for Heat Removal. In Refrigerated Space Temperature column get the Box Temperature of 45°F from step 3, Ambient Temperature of 100°F from step 2, Relative Humidity of 50 percent from the problem. Go across from 45°F to 100°F. Come down the column under 50 percent to 2.47. Now multiply 309 X 34.5 X 2.47 for the total refrigeration load of 26331 Btu for 24 hours.

Step 14. Product Load. Enter the weight of the product. Subtract the box temperature from the product's entering temperature. Get the Specific Heat from Table 2. Multiply 1650 X 10 X . 96 for the total load of 15840 Btu for 24 hours.

Step 15. Heat of Respiration Load. Write in the weight of the product. Get the Heat of Respiration from Table 2 for lettuce. Multiply 1650 X 3. 69 for the total load of 6089 Btu per 24 hours.

Step 16. Miscellaneous Loads. Multiply the total wattage of 100 times the burning times of two hours times 3. 42, the number of Btu one watt puts out in one hour. This gives a total load of 684 Btu for 24 hours. To get the motor load, multiply the motor horsepower of 1/8 times 4250, the amount of Btu a one horsepower motor will put out in one hour (as used in the school) times 24 hours of operating itme. This gives a total of 12750 Btu per 24 hours.

Step 17. To get the total refrigeration load add all 24 hour totals. Get 10 percent of the total load, 10393, and add it to the total load to get 114327 Btu per 24 hours of operation.

Step 18. Required Hourly Capacity. Since a condensing unit will operate 16 hours out of 24 when the box temperature is above 32°F, and operate 18 hours when the box temperature is below 32°F, then the required hourly capacity may be found by dividing 16 into 114327 for 7145 Btu hour removal.

The same steps may be used to work a heat load problem on a box with a temperature below 32°F with two exceptions.

Use the quick freeze temperature of a product when it is to be frozen and moved out within 24 hours.

To find temperature reduction to freezing, subtract the product's freezing point from its entering temperature.

To find temperature reduction below freezing subtract the quick freeze temperature of the product from the product's freezing temperature.

The information that has been given to you will familiarize you with the necessity of accurately sizing and selecting the type of unit to be used. Many quick reference charts have been devised and are available to the serviceman, however they should not be used as the sole reference for sizing refrigeration equipment but rather as an aid in determining at a glance if a unit were extremely undersized or oversized. It could also be used as an estimate for anticipating unit costs.

Sizing Evaporators and Condensing Units. After completing the load estimate form, the next step is to select an evaporator and condensing unit for the system. The evaporator is usually selected from manufacturer's charts, using temperature difference, temperature range, and hourly heat load. The condensing unit is selected from manufacturer's charts using hourly heat load and suction temperature.

(FOR ROOMS ABOVE 32°F)

DESIGN INFORMATION

Application:
Outside Ambient Temperature: 100 °F
Room Temperature: 45 °F
Temperature Difference(TD) 55 °F

Room Dimensions Outside
Length(L) 8 ft
Width (W) 6 ft
Height (H) 8 ft

Insulation
Type Fib.
Thickness 3 in

Overall Wall Thickness:
Product Load:
Lettuce
1650 Pounds at 55°F

Miscellaneous Loads
Number of People NONE
Electrical watts 100 W- 2hrs.
Other: Motor 1/8 hp - 24 hrs.

SOLUTION

Outside Room Surface Area (A)

Front	64	Bottom	48
Back	64	L. End	48
Top	48	R. End	48

Total 320 sqft

Room Dimension Inside
Length 7.5 ft
Width 5.5 ft
Height 7.5 ft
V = (Calculate on separate sheet)
V = 309. 375 cu ft

I WALL LOAD
(a) Area 320 sq ft
(b) Wall heat gain factor 132 Btu/sq ft/24 hrs
(c) Total load . . . . 42,240 Btu/24 hrs

II AIR CHANGE LOAD
(a) Volume 309 cu ft
(b) Air changes 34.5 per 24 hrs
(c) Heat removal 2.47 Btu/cu ft
(d) Total load . . . . 26,331 Btu/24 hrs

III PRODUCT LOAD
1. Temperature reduction load
(a) Weight of product 1650 lbs
(b) Temperature reduction 10 °F
(c) Specific heat .96 Btu/lb°F
(d) Load . . . . 15,840 Btu/24 hrs
2. Heat of respiration load
(a) Weight of product 1650 lbs
(b) Heat of respiration 3.69 Btu lb
(c) Load . . . . 6089 Btu/24 hrs

IV MISCELLANEOUS LOADS

(a) People	None	X		X		=		Btu/24 hrs
(b) Watts	100	X	3.42	X	2 hrs.	=	684	Btu/24 hrs
(c) Other	1/8 hp	X	4250	X	24 hrs.	=	12,750	Btu/24 hrs

V TOTAL REFRIGERATION LOAD 103,934 Btu/24 hrs
VI SAFETY FACTOR (10% of total refrigeration load) 10,393 Btu/24 hrs
VII TOTAL REFRIGERATION LOAD WITH SAFETY FACTOR 114327 Btu/24 hrs
VIII REQUIRED HOURLY CAPACITY = 114,327 X 1/16 hrs 7,145 Btu/hrs

Figure 85. Load Estimate Form.

Whenever the temperature of an evaporator is lowered, its capacity will increase because it will remove more Btu. Any increase or decrease of the temperature difference between the evaporator and refrigerated space would cause an increase or decrease in box humidity. If the temperature difference is too large, the evaporator will remove too much moisture from the air causing food dehydration. If the temperature difference is too little, it will not remove enough moisture, causing sliming and molding of food. Care should be taken to properly size the evaporator to be sure of efficient operation.

The condensing unit capacity depends upon suction temperature, types of condensing units and temperature ranges. When the suction temperature decreases, the efficiency of the compressor decreases because the amount of refrigerant available to the compressor is not as much as it was when the suction temperature was high.

Select an evaporator and condensing unit using the following procedure. Select the evaporator first. Use the heat load problem on lettuce.

Step 1. Use Table 8 to get the box temperature for the product in the column under the heading, "Cooler Temperatures." Use the lowest temperature. Mixed vegetables and fruits will be the product.

Step 2. From the same table get the temperature difference in the fourth column.

Step 3. Get the hourly heat load from the load estimate form. In cases where this information is not given but the 24-hour heat load is given, divide this heat load by the condensing unit running time. This gives the hourly heat load. This number will be used as a reference number to locate the Btu rating. Write this number in the blank provided.

Step 4. Go to Table 9. Look under temperature difference from step 2 and get the Btu rating. This number is nearest but larger than the reference number in step 1.

Step 5. The model number is found in Table 9 to the left of the Btu rating.

The condensing unit must now be selected. Use an air-cooled unit.

Step 1. Get the evaporator suction temperature from Table 8.

Step 2. Use Table 10 to locate the Btu rating. Look under the heading, "Evaporator Suction Temperature" and select a number that is nearest but greater than the reference number.

Step 3. The model number, compressor motor horsepower and refrigerant will be located on the same chart to the left of the Btu rating.

This contains the information from the preceding steps.

Evaporators		Condensing Units	
Box temperature	45 °F	Evaporator suction temp	35
Temperature difference	10°F	Btu rating	6675-8150
Reference number	7145	Model number	"D"
Btu rating	8500	Compressor motor hp	3/4
Model number	4, 13, or 20	Refrigerant used	12

Use the preceding procedure to work the following problem. Use Table 11 for the water-cooled condensing unit.

This walk-in is utilized to store frozen meats. The total heat load is 143,000 Btu per 24 hours. Select a condensing unit that uses water as a cooling medium. If Table 11 does not have the evaporator suction temperature as listed in Table 8, use the next lower evaporator suction temperature.

Evaporator		Condensing Unit	
Box Temperature	-5° to +5°F	Evaporator suction temp	-15° to -5°F
Temperature difference	10°F	Btu rating	8325-11,190
Reference number	7944	Model number	"H"
Btu rating	8500	Compressor motor hp	2hp
Model number	4, 13, or 20	Refrigerant used	12

SUMMER TEMPERATURE

State	City	Dry Bulb °F	State	City	Dry Bulb °F
Alabama	Birmingham	95	Mississippi	Vicksburg	95
	Mobile	95	Missouri	Kansas City	100
Arizona	Phoenix	105		St Louis	95
	Tucson	105	Montana	Billings	90
Arkansas	Fort Smith	95		Helena	95
	Little Rock	95	Nebraska	Lincoln	95
California	Bakersfield	105		Omaha	95
	Fresno	105	Nevada	Reno	95
	Los Angeles	90	New Hampshire	Concord	90
	San Francisco	85	New Jersey	Atlantic City	95
Colorado	Denver	95		Newark	95
Connecticut	Hartford	93		Trenton	95
	New Haven	95	New Mexico	Albuquerque	95
Delaware	Dover	93		Santa Fe	90
	Wilmington	95	New York	Albany	93
District of Columbia	Washington	95		Buffalo	93
				New York	95
Florida	Jacksonville	95	North Carolina	Asheville	93
	Key West	98		Charlotte	95
	Miami	91		Raleigh	95
	Tampa	95	North Dakota	Bismarck	95
Georgia	Atlanta	95	Ohio	Cincinnati	95
	Savannah	95		Cleveland	95
Idaho	Boise	95	Oklahoma	Oklahoma City	101
Illinois	Chicago	95		Tulsa	101
	Peoria	96	Oregon	Portland	90
	Springfield	98	Pennsylvania	Erie	93
Indiana	Evansville	95		Pittsburgh	95
	Fort Wayne	95	Rhode Island	Providence	93
	Indianapolis	95	South Carolina	Charleston	95
	Terre Haute	95		Greenville	95
Iowa	Des Moines	95	South Dakota	Huron	95
	Sioux City	95		Rapid City	95
Kansas	Dodge City	95	Tennessee	Knoxville	95
	Topeka	100		Memphis	95
	Wichita	100	Texas	Corpus Christi	95
Kentucky	Louisville	95		Dallas	100
Louisiana	New Orleans	95	Utah	Salt Lake City	95
	Shreveport	100	Vermont	Burlington	90
Maine	Eastport	90	Virginia	Norfolk	95
	Portland	90	Washington	Seattle	85
Maryland	Baltimore	95		Spokane	93
Massachusetts	Boston	92	West Virginia	Charleston	95
	Springfield	93	Wisconsin	Green Bay	95
Michigan	Detroit	95		Madison	95
	Grand Rapids	95		Milwaukee	95
	Lansing	95	Wyoming	Cheyenne	95
Minnesota	Duluth	93			
	Minneapolis	95			

Table 1.

PRODUCTION STORAGE INFORMATION

	Freezing Point	Quick Freezing Temp	Short Storage Temp.	Latent Heat	Heat of Respiration	Specific Heat	
						Above Freezing	Below Freezing
Apples	28.4	-15	38	121	0.72	0.86	0.45
Asparagus	29.8	-30	40	134.0	5.75	0.94	0.48
Beans, Green	29.7		40	128	3.37	0.91	0.47
Beans, Dried	28		50	18		0.30	0.24
Beef, Fresh	28	-15	38	79		0.60	0.35
Blackberries	28.9	-15	42	122		0.88	0.46
Butter	30.0	+15	40	15		0.64	0.34
Cabbage	31.2	-30	45	132		0.94	0.47
Carrots	29.6	-30	40	126	1.73	0.86	0.45
Celery	29.7	-30	45	135	2.27	0.95	0.48
Cheese, American	17.0	+15	39	79	2.34	0.64	0.36
Cherries	26.0		40	120	1.32	0.87	0.45
Chocolate, Coating	15-25			40		0.3	0.55
Corn, Green	28.9		45	108	4.1	0.80	0.43
Cranberries	27.3		40	124		0.90	0.46
Cream (40%)	28.0		40	90		0.85	0.40
Eggs, Fresh	27.0	-10	38	100		0.76	0.40
Fish, Iced	30.0	-15	25	101		0.76	0.41
Fish, Dried				65		0.56	0.34
Grapes	26.3		35	116	0.42	0.88	0.44
Ham, Fresh	27.0		36	87.7		0.68	0.38
Ice Cream	27.0	-20	0	96		0.78	0.45
Lemons	28.1		55	127	0.41	0.92	0.46
Lettuce	31.2		45	136	3.69	0.96	0.48
Lobster, Boiled			36	105		0.81	0.42

Table 2.

WALL HEAT GAIN CHART

Insulation Thickness in Inches	Temperature Difference in °F (Ambient minus Storage Temp)																	
	1	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120
3	2.4	96	108	120	132	144	156	168	180	192	204	216	228	240	252	264	276	288
4	1.8	72	81	90	99	108	117	126	135	144	153	162	171	180	189	198	207	216
5	1.44	58	65	72	79	87	94	101	108	115	122	130	137	144	151	159	166	173
6	1.2	48	54	60	66	72	78	84	90	96	102	108	114	120	126	132	138	144
7	1.03	41	46	52	57	62	67	72	77	82	88	93	98	103	108	113	118	124
8	0.90	36	41	45	50	54	59	63	68	72	77	81	86	90	95	99	104	108
9	0.80	32	36	40	44	48	52	56	60	64	68	72	76	80	84	88	92	96
10	0.72	29	32	36	40	43	47	50	54	58	61	65	68	72	76	79	83	86

Table 3.

AIR CHANGES FOR ROOMS BELOW 32°

24-Hour Air Changes	Volume Cu. Ft.	24-Hour Air Changes	Volume Cu. Ft.	24-Hour Air Changes	Volume Cu. Ft.
33.5	200	15.3	800	5.6	5,000
29.0	250	13.5	1000	5.0	6,000
26.2	300	11.0	1500	4.3	8,000
22.5	400	9.3	2000	3.8	10,000
20.0	500	7.4	3000	3.0	15,000
18.0	600	6.3	4000	2.6	20,000

Table 4A.

AIR CHANGES FOR ROOMS ABOVE 32°

24-Hour Air Changes	Volume Cu. Ft.	24-Hour Air Changes	Volume Cu. Ft.	24-Hour Air Changes	Volume Cu. Ft.
44.0	200	20.0	800	7.2	5,000
38.0	250	17.5	1000	6.5	6,000
34.5	300	14.0	1500	5.5	8,000
29.5	400	12.0	2000	4.9	10,000
26.0	500	9.5	3000	3.9	15,000
23.0	600	8.2	4000	3.5	20,000

Table 4B.

HEAT REMOVED IN REFRIGERATED SPACE

Refrig Space Temp °F	Ambient Temperature °F							
	85		90		95		100	
	Relative Humidity %							
	50	60	50	60	50	60	50	60
65	0.65	0.85	0.93	1.17	1.24	1.54	1.58	1.95
60	0.85	1.03	1.13	1.37	1.44	1.74	1.78	2.15
55	1.12	1.34	1.41	1.66	1.72	2.01	2.06	2.44
50	1.32	1.54	1.62	1.87	1.93	2.22	2.28	2.65
45	1.50	1.73	1.80	2.06	2.12	2.42	2.47	2.85
40	1.69	1.92	2.00	2.26	2.31	2.62	2.67	3.06
35	1.86	2.09	2.17	2.43	2.49	2.79	2.85	3.24
30	2.00	2.24	2.26	2.53	2.64	2.94	2.95	3.35

Refrig Space Temp °F	Ambient Temperature °F							
	40		50		90		100	
	Relative Humidity %							
	70	80	70	80	50	60	50	60
30	0.24	0.29	0.58	0.66	2.26	2.53	2.95	3.35
25	0.41	0.45	0.75	0.83	2.44	2.71	3.14	3.54
20	0.56	0.61	0.91	0.99	2.62	2.90	3.33	3.73
15	0.71	0.75	1.06	1.14	2.80	3.07	3.51	3.92
10	0.85	0.89	1.19	1.27	2.93	3.20	3.64	4.04
5	0.98	1.03	1.34	1.42	3.12	3.40	3.84	4.27
0	1.12	1.17	1.48	1.56	3.28	3.56	4.01	4.43
-5	1.23	1.28	1.59	1.67	3.41	3.69	4.15	4.57
-10	1.35	1.41	1.73	1.81	3.56	3.85	4.31	4.74
-15	1.50	1.53	1.85	1.92	3.67	3.96	4.42	4.86

Table 5.

BTU/HR/HP		
Motor Motor Hp	Load Inside Refrigerator	Loss Outside Refrigerator
1/8 to 1/2	4250	2545
1/2 to 3	3700	2545
3 to 20	2950	2545

Table 6. Btu Given off by Electric Motors.

EVAPORATOR SUCTION TEMPERATURE								
	Model of Compressor	Refrig	Hp	20°	25°	30°	40°	50°
High Temp Units	A-1	22	2	11,000	13,000	16,000	21,000	26,000
	A-2	12	2	15,300	16,000	18,000	21,000	25,000
	A-3	22	3	22,000	24,000	26,000	32,000	39,000
	A-4	12	3	23,000	26,000	29,500	35,500	41,500
	A-5	22	4	28,000	33,000	38,000	48,000	56,000
	A-6	12	4	30,000	33,000	36,000	43,000	52,000
	A-7	22	5	41,000	46,000	51,000	62,000	72,000

EVAPORATOR SUCTION TEMPERATURE								
Medium Temp Units	Model of Compressor	Refrig	Hp	0°	10°	20°	25°	
	A-8	12	1 1/2	8,500	10,500	12,500	13,000	

EVAPORATOR SUCTION TEMPERATURE								
	Model of Compressor	Refrig	Hp	-30°	-30°	-10°	0°	+10°
Low Temp Units	A-9	12	2	5,000	7,000	9,000	12,000	16,000
	A-10	12	3	8,000	11,000	14,000	17,000	22,000

Table 7.

Temperatures for Refrigerators and Coolers

Product	Temperature	Suction Pres Temp.	Temp Difference
Fresh Meats	Cooler 34° to 38° Cases 38° to 42°	20° 20° to 25°	12° to 15°
Frozen Meats	-5° to +5°	-15° to -5°	10°
Butter & Eggs	Storage Temp. 31° to 36° Serving Temp. 50° to 60°	15° 30°	15° 15° to 20°
Vegetables & Fruits	35° to 45°	25° to 30°	10°
Milk	Water Cooling 36° to 38° Cooler Storage 36° to 40°	15° to 20° 20°	15° to 20°
Ice Cream	-20°	-30°	5° to 10°
Beer	36° to 45°	20°	15° to 20°

Table 8.

STANDARD UNIT COOLER

	Btu per hour	
Model	10° TD	15° TD
1	3,500	5,250
2	4,500	6,750
3	6,500	9,750
4	8,500	12,750
5	10,500	15,750
6	12,000	18,000
7	18,000	27,000
8	24,000	36,000
9	32,000	48,000

WALL JET COOLER

	Btu per hour	
Model	10° TD	15° TD
10	3,500	5,250
11	4,500	6,750
12	6,500	9,750
13	8,500	12,750
14	10,500	15,750
15	12,000	18,000
16	18,000	27,000
17	24,000	30,000

CEILING JET COOLER

	Btu per hour	
Model	10° TD	15° TD
18	4,500	6,750
19	6,500	9,750
20	8,500	12,750
21	10,500	15,750

Table 9. Evaporator Selection Charts.

Unit	Hp	Refrig	Suction Temperature			
			20°	25°	30°	40°
A	1/4	12	1,910	2,110	2,320	2,780
B	1/3	12	2,250	2,520	2,780	3,325
C	1/2	12	3,480	3,850	4,320	5,400
D	3/4	12	5,200	5,960	6,675	8,130
E	1	12	7,400	8,200	9,100	11,000

Table 10. Air-Cooled Condensing Units.

Unit	Hp	Refrig	Btu/Hr	Suction Temperature				
				-30°	-20°	-10°	0°	10°
F	1	12	Btu/Hr	3,000	4,300	5,850	7,650	
G	1-1/2	12	Btu/Hr	3,970	5,400	7,160	9,330	
H	2	12	Btu/Hr	5,860	8,325	11,190	14,800	19,080
I	3	12	Btu/Hr	8,450	11,620	15,280	19,780	25,000

Table 11. Water-Cooled Condensing Units.

SUMMARY

This unit of instruction has presented information which will develop the knowledge and skill necessary in calculating the size of any refrigeration machine, as to the amount of heat the evaporator and condensing unit must remove and why the various parts of a system must be a certain size.

The successful installation and future operation of refrigeration systems depends on matching the capacity of the condensing unit and evaporator to the heat load. A careful review of the material presented will prove invaluable in the future.

REFERENCES

Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.

REFRIGERANTS

STUDY ASSIGNMENT: Modern Refrigeration and Air Conditioning, paragraphs 9-1 through 9-23.

STUDY NOTES

Paragraphs 9-1, 2

Certain properties of refrigerants are more important than others. The characteristics of an ideal refrigerant are covered in paragraph 9-1.

Refrigeration machines operate year in and year out without constant attention from personnel. The refrigerants used should be outstanding in the following:

1. Nontoxic
2. Nonpoisonous
3. Nonflammable or explosive
4. Low operating pressure, but not in a vacuum
5. Noncorrosive
6. Very stable
7. Low volumes per unit heat to keep machine sizes to a minimum

The tables on pages 320 and 1061 are very informative giving the chemical name and formulas of popular refrigerants and the properties of each.

Paragraph 9-3, 4

Safety is all important in dealing with refrigerants. The National Refrigeration Safety Code has divided the refrigerants into three groups. Group one refrigerants, which are the safest, are used most often.

You should practice reading the curves shown on figure 9-2. They enable you to find quickly the pressure of a refrigerant if you know the temperature. Using the R-12 curve,

1. locate the pressure on the horizontal line or scale;

2. go vertically, until you come to the R-12 curve;

3. go horizontally to the left until you reach the temperature scale.

Paragraphs 9-5 through 15

These paragraph discuss the various refrigerants and give information you must know to properly maintain and service systems.

Paragraphs 9-17, 18

The refrigeration specialist should become very familiar with the R-number, the refrigerant name, chemical formula, and boiling temperature of the most popular refrigerants.

Paragraphs 9-19, through 23

Men who study refrigerants often ask the following questions:

1. What should the high side pressure be?
2. What should the low side pressure be?
3. How much refrigerant should be in a system?

Careful study of the above paragraphs will answer these questions.

Paragraphs 9-17 through 31

Never change refrigerants unless it is absolutely necessary. Each refrigerant is different. Each machine is specifically designed for a specific refrigerant. It is a good bet that no good will come from attempting to change or mix refrigerants.

Paragraphs 9-32

Always play it safe when working with refrigerants. Wear goggles at all times when charging or discharging systems.

SUMMARY

You already know a great deal about refrigerating machines and what a refrigerant must do inside the machine. The story of refrigerants gives an interesting picture of the development of refrigeration. Understanding the physical and chemical properties will aid you greatly if you give serious study to this subject.

PRESSURE-ENTHALPY DIAGRAM

STUDY ASSIGNMENT: Modern Refrigeration and Air Conditioning, paragraphs 16-31 through 16-51.

STUDY NOTES

Paragraphs 16-31 through 38

Understanding the pressure-enthalpy diagram (pressure-heat) will require careful study. Two things you must remember about the P-E chart is that it is based on one pound of refrigerant, and each refrigerant has its own chart or diagram.

Paragraphs 16-42 through 48

The diagrams show the effects of various common refrigeration troubles. Understanding these effects will give you a much better explanation of certain refrigeration problems.

Paragraphs 16-49, 50, and 51

The compressor is simply a pumper of heat-laden vapor. Each cubic inch of vapor holds a number of Btu that was picked up by it in the evaporator. Mathematical formulas are the only way to find out how many cubic inches of vapor are pumped by the compressor. Once you find out the inches pumped, you can easily find how many Btu are represented.

There is always some refrigerant vapor left in the space between the top of the piston and the cylinder head at the end of the compression stroke. This space is termed mechanical clearance/or volumetric clearance and must be as low as possible. Be careful when servicing so as not to make any mistakes that may result in low efficiencies.

SUMMARY

A thorough knowledge of the refrigeration cycle requires study of not only the individual processes that make up the cycle, but the relationship between the processes.

This is simplified by the use of charts and diagrams by which the cycle is shown graphically. Through the use of these charts and diagrams, troubleshooting of refrigerating systems in a logical manner is possible. Careful study of the diagrams and explanations presented are a valuable asset to the serious student of refrigeration.

REFERENCES

Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano

Workbooks 3AZR54550-2-I-2-P1 thru I-3-P4

Department of Civil Engineering Training

Refrigeration and Air Conditioning Equipment

REFRIGERATION AND AIR-CONDITIONING SYSTEMS

September 1974

SHEPPARD AIR FORCE BASE

11-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

PROJECT	TITLE	PAGE
I-2-P1	Identify Electrical Units, Construct and Analyze Current Flow in a Circuit	1
I-2-P2	Multimeter Reading and Circuit Construction	9
I-2-P3	Circuit Analysis	29
I-2-P4	Reading a Motor Data Plate, Motor Construction and Wiring	41
I-2-P5	Troubleshooting AC Circuits	59
I-3-P1	Major Components and Refrigerant Flow Through a System	69
I-3-P2	Calculating Heat Loads and Equipment Selection	71
I-3-P3	Plotting the Refrigeration Cycle With the Pressure-Enthalpy Diagram	75
I-3-P4	Plotting the Refrigeration Cycle and Checking the Operation and Efficiency of a System Using the PE Diagram	77

This supersedes SW 3AZR54550-2-I-1-4 and WB 3AZR54550-1-2-P1 through I-4-P7, 3 January 1973.

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-I-2-P1
3 September 1974

IDENTIFY ELECTRICAL UNITS, CONSTRUCT AND ANALYZE CURRENT FLOW IN A CIRCUIT

OBJECTIVES:

Upon completion of this project you will be able to:

Construct an operative simple circuit using a dc power source, a protective device, a switch, a lamp, and an ammeter.

Analyze the current flow through the simple dc circuit while observing all applicable safety precautions.

Standard of performance:

The standard of performance of this project is 100 percent completion, errorfree.

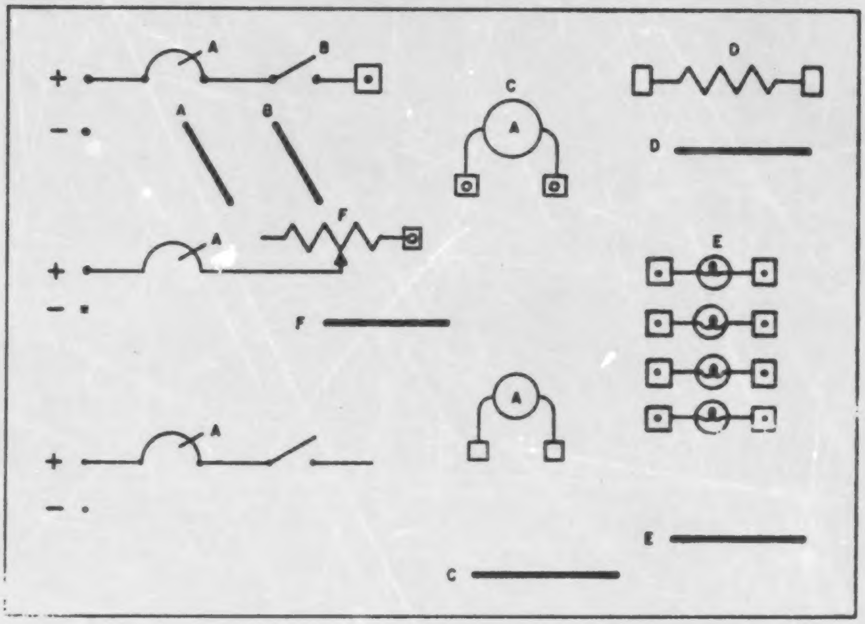
EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-I-2-P1	1/student
Pen or pencil	1/student

PROCEDURE

PART I

IDENTIFICATION OF UNITS ON THE TRAINER

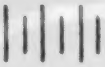


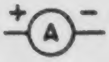
A Diagram of the Trainer

1. Above is a diagram of the trainer to which you have been assigned. Under each unit on the diagram is a space provided to write the name of the unit. Identify each unit by writing its nomenclature on the heavy black line.

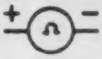
)

2. Beside each of the following symbols, write its name.

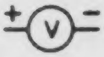
a.  Name______________________

b. 

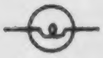
Name______________________

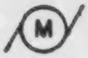
c. 

Name______________________

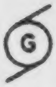
d. 

Name______________________

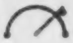
e.  Name______________________

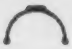
f. 

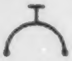
Name______________________

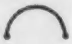
g. 

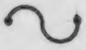
Name______________________

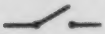
h.  Name______________________

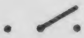
i.  Name______________________

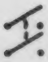
j.  Name______________________

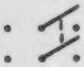
k.  Name______________________

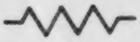
l.  Name______________________________

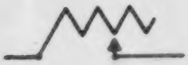
m.  Name______________________________

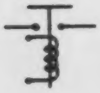
n.  Name______________________________

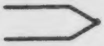
o.  Name______________________________

p.  Name______________________________

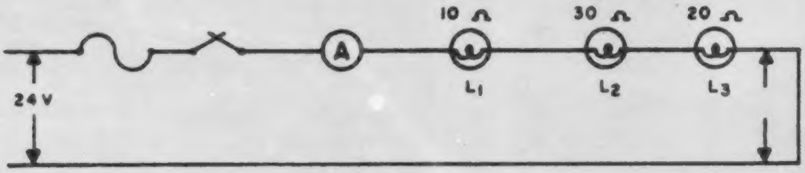
q.  Name______________________________

r.  Name______________________________

s.  Name______________________________

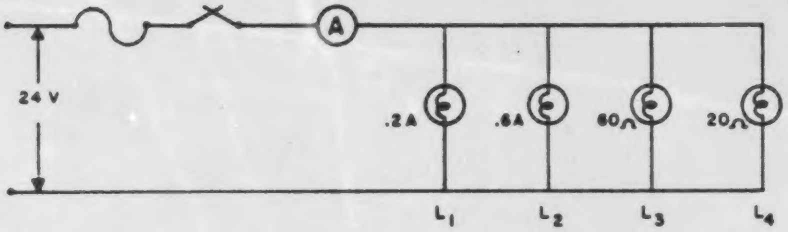
t.  Name______________________________

3. **Identify the circuits below as series or parallel circuits.**



10 Ω
30 Ω
20 Ω
A
L1
L2
L3
24 V

A. ______________________________



A
24 V
.2 A
.6 A
60 Ω
20 Ω
L1
L2
L3
L4

B. ______________________________

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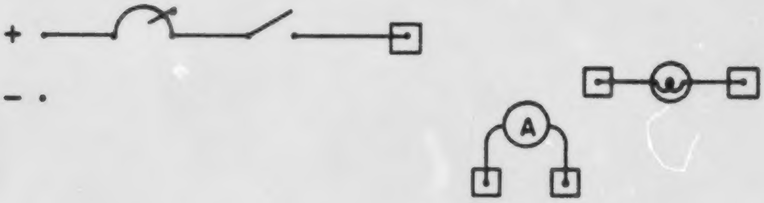
PART II

CURRENT FLOW ANALYSIS AND CIRCUIT CONSTRUCTION

1. Before wiring any electrical circuit, a diagram of the circuit should be drawn. The units to be included in the diagram are a circuit breaker, a SPST switch, an ammeter, and a light. Draw lines on the following diagram to represent the wires you will place on the trainer.



2. Have the instructor check your diagram.

CAUTION: Remove all jewelry.

3. Wire the circuits on the trainer assigned to you by the instructor. Use your diagram as a guide.

NOTE: Use the larger bulb.

4. Have the instructor check your wiring.

5. Turn the circuit breaker and the switch to the ON position.

a. How much current is in the circuit?____________________________

b. What meter is used to measure current?____________________________

c. What is the unit of measure for current?____________________________

d. What is current?____

6. Turn the switch OFF.

7. Replace the bulb with a smaller bulb.

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8. **Turn the switch ON.**

   a. **How much current is in the circuit?** ________________________

   b. **Did current increase, decrease, or remain the same?** ____________

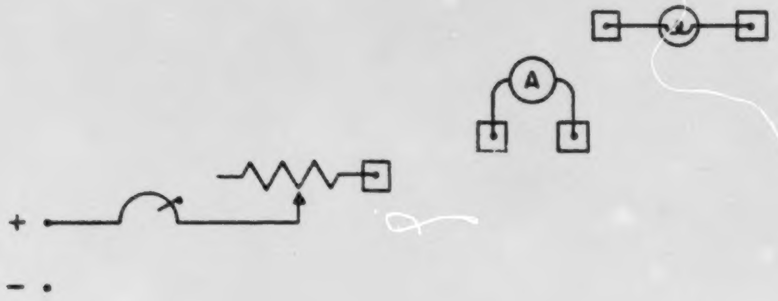
   c. **Why?** ____

   d. **What determines the amount of current flow in the circuit?** __________

   ____

Remove All Wires

9. The units to be included in the circuit are a circuit breaker, a rheostat, an ammeter, and a light. Draw lines on the following diagram to represent the wires you will place on the trainer.



10. Have the instructor check your diagram.

11. Wire the circuit on the trainer.

12. Have the instructor check your wiring.

13. Turn the circuit breaker to the ON position.

14. Turn the rheostat as far to the left as you can without turning the light off.

    a. How much current is in the circuit? ________________________

    b. Does the light burn "bright" or "dim?" ________________________

15. Turn the rheostat as far to the right as possible without turning the light off.

Checked by ________________________
Instructor

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-I-2-P2

MULTIMETER READING AND CIRCUIT CONSTRUCTION

OBJECTIVES:

Upon completion of this project you will be able to:

Use multimeter to measure voltage and resistance of circuits.

Construct an operative series circuit.

Construct an operative parallel circuit.

Determine the unknown electrical factors for each circuit by using Ohm's Law and the characteristics of each type of circuit.

Standard of performance

The standard of performance of this project is 100 percent completion, errorfree.

EQUIPMENT

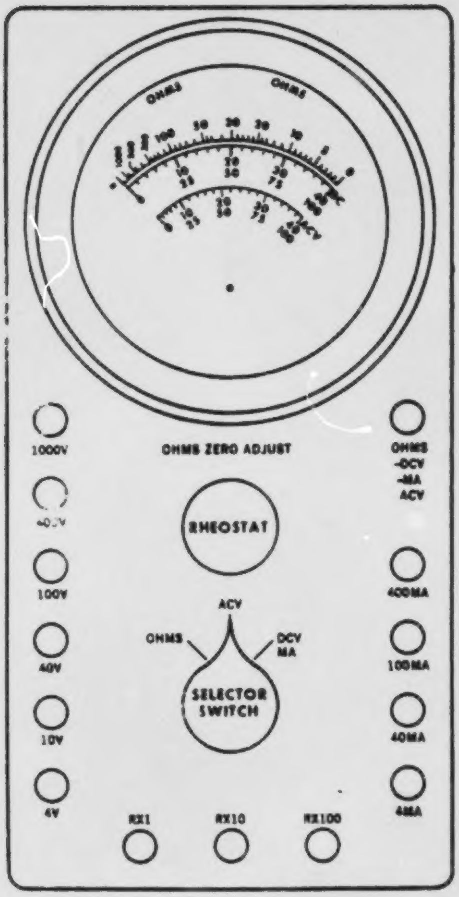
	Basis of Issue
WB 3AZR54550-2-I-2-P2	1/student
Trainer, Multimeter Reading	1/12 students
Trainer, Multimeter	1/12 students
Pen or pencil	1/student

PROCEDURE

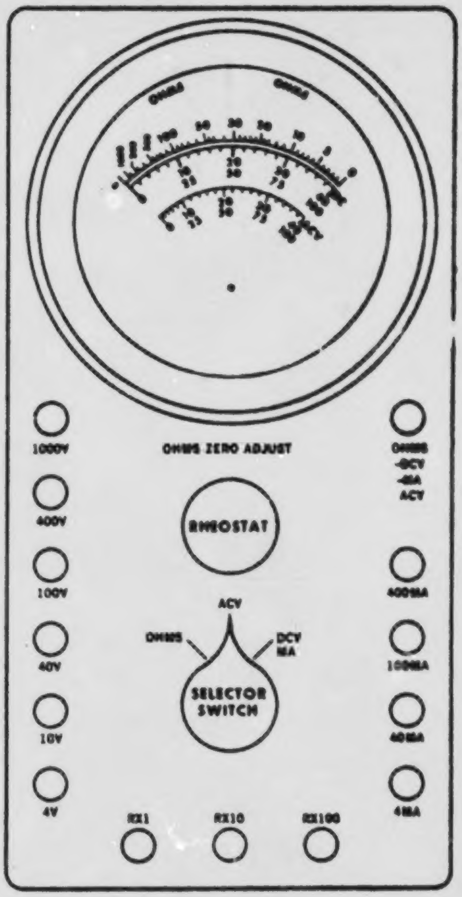
PART I

USING THE MULTIMETER AS A DC VOLTMETER

1. Draw, on the following meter faces, the indication needle in its proper position. Then fill in the blanks below the meter faces to show the proper setting of switch knob and range jack for the meter indication given.


OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100

Indicating 24 V dc
Switch Knob________________
Range Jack________________

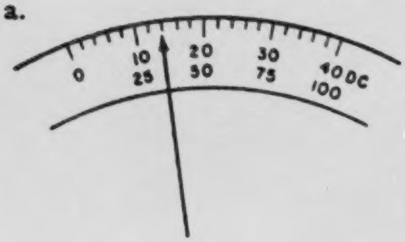

OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100

Indicating 1.5 V dc
Switch Knob________________
Range Jack________________

2F -75-658

2. In the diagrams below, different range jacks are listed below each meter face. Write what the meter would be indicating on each specific range in the blanks provided.

a.



0
10
20
30
40
DC
25
50
75
100

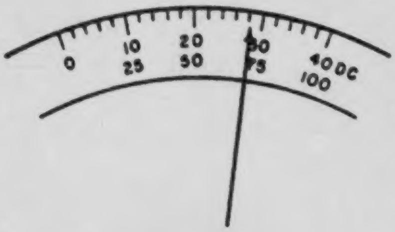
Range Jack **Reading**

1000 V__________Volts

100 V__________Volts

10 V__________Volts

b.



0
10
20
30
40
DC
25
50
75
100

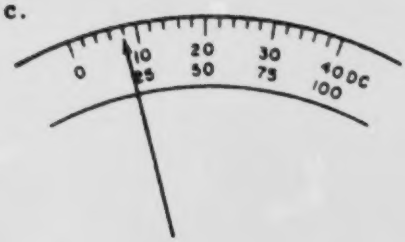
Range Jack **Reading**

400 V__________Volts

40 V__________Volts

4 V__________Volts

c.



0
10
20
30
40
DC
25
50
75
100

Range Jack **Reading**

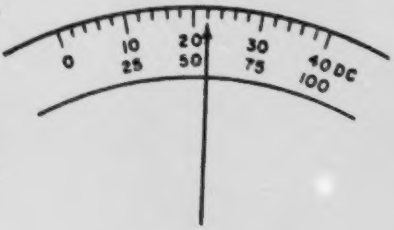
100 V__________Volts

4 V__________Volts

1000 V__________Volts

10 V__________Volts

d.



0
10
20
30
40
DC
25
50
75
100

Range Jack **Reading**

40 V__________Volts

100 V__________Volts

10 V__________Volts

4 V__________Volts

3. On the trainer assigned to you by the instructor, put the trainer cord plug in a 110V ac receptacle.

4. Set the trainer switch to DC position.

NOTE: Red light should burn.

5. Set the multimeter to measure dc voltages.

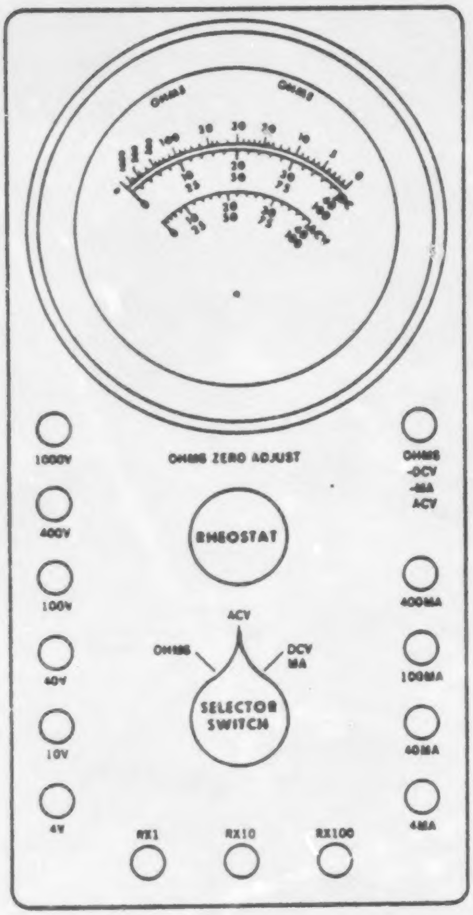
6. Make and record voltage measurements between trainer terminals indicated below.

Trainer Terminals	Voltage
1 to 2	
2 to 17	
3 to 6	
4 to 8	
4 to 17	
5 to 10	
6 to 12	
7 to 14	
10 to 13	
12 to 17	
14 to 16	
14 to 18	
15 to 17	
16 to 17	
17 to 18	

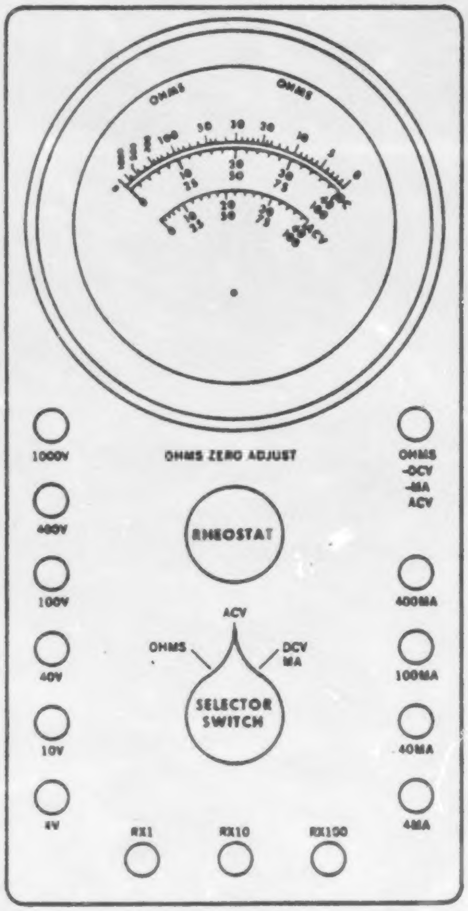
PART II

USING THE MULTIMETER AS AN AC VOLTMETER

1. Draw, on the following meter faces, the indicating needle in its proper position. Then fill in the blanks below the meter faces to show the proper setting of switch knob and range jack for the meter indication given.


OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100

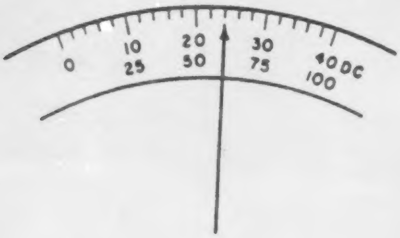
Indicating 110V AC
Switch Knob________________
Range Jack________________


OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100

Indicating 220V AC
Switch Knob________________
Range Jack________________

2. In the diagrams below, different range jacks are listed below each meter face. Write what the meter would be indicating on each specific range in the blanks provided.

a.



Range Reading

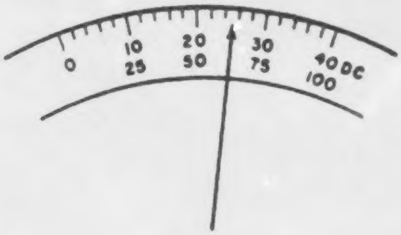
100 V____________Volts

40 V____________Volts

10 V____________Volts

1000 V____________Volts

b.



Range Reading

4 V______________Volts

100 V______________Volts

400 V______________Volts

1000 V______________Volts

3. Set the trainer switch to AC position.

NOTE: Red light does not burn.

4. Set the multimeter to measure ac voltages.

5. Make and record voltage measurements between trainer terminals indicated below.

Trainer Terminals	Voltages
2 to 17	
4 to 17	
1 to 2	
3 to 6	
5 to 10	
6 to 12	
7 to 14	

10 to 13 ____________________

12 to 17 ____________________

14 to 16 ____________________

14 to 18 ____________________

15 to 17 ____________________

16 to 17 ____________________

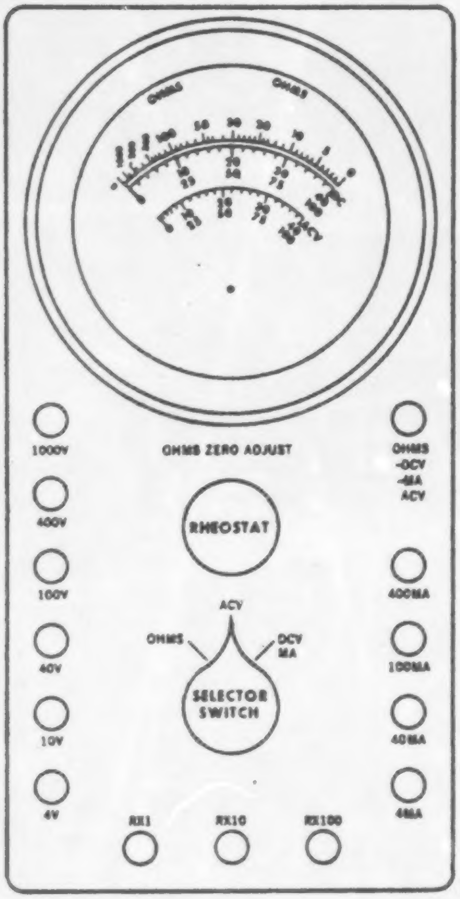
17 to 18 ____________________

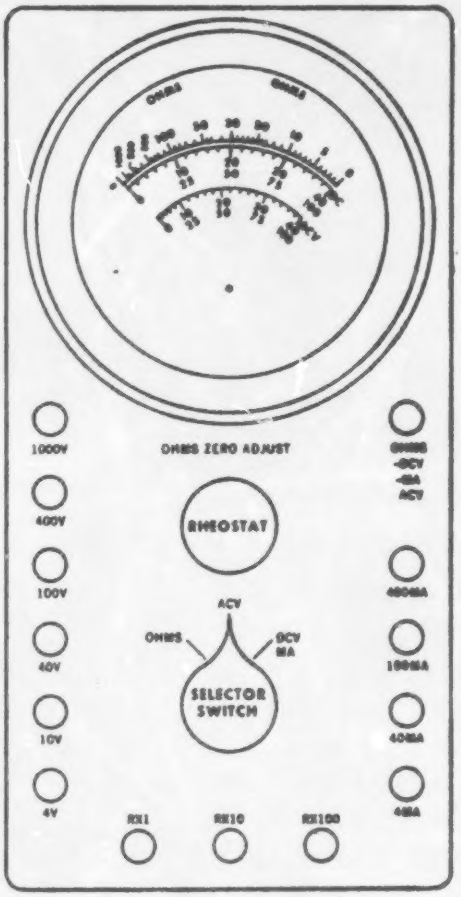
6. Unplug the trainer.

PART III

USING THE MULTIMETER AS AN OHMMETER

1. Draw, on the following meter faces, the indicating needle in its proper position. Then fill in the blanks below the meter faces to show the proper setting of switch knob and range jack for the meter indication given.


OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100


OHMS
OHMS
1000V
400V
100V
40V
10V
4V
OHMS ZERO ADJUST
RHEOSTAT
ACV
OHMS
DCV MA
SELECTOR SWITCH
OHMS -DCV -MA ACV
400MA
100MA
40MA
4MA
RX1
RX10
RX100

Indicating 5 Ohms

Switch Knob________________

Range Jack________________

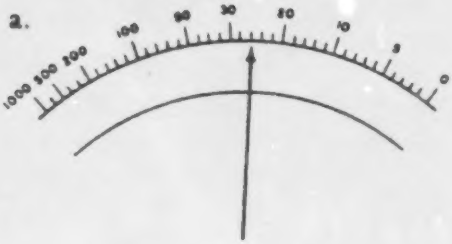
Indicating 2000 Ohms

Switch Knob________________

Range Jack________________

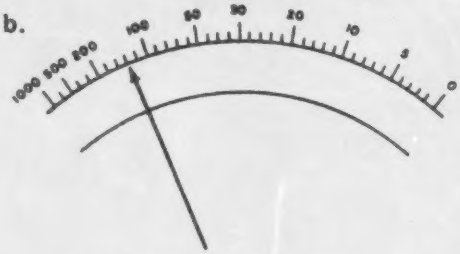
2. In the diagrams below, different range jacks are listed below each meter face. Write what the meter would be indicating on each specific range in the blanks provided.

a.


1000
500
200
100
50
30
20
10
5
0

Range	Reading
R x 1	
R x 10	
R x 100	

b.


1000
500
200
100
50
30
20
10
5
0

Range	Reading
R x 1	
R x 10	
R x 100	

3. Set the trainer switch to the OHMS position.

4. Set the multimeter to measure resistance.

5. Make and record measurements between trainer terminals indicated below.

Trainer Terminals	Resistance
1 to 3	
1 to 5	
1 to 11	
2 to 10	
2 to 12	
3 to 13	
4 to 10	
5 to 11	
5 to 13	
7 to 9	
8 to 16	
9 to 17	

10 to 12 ____________________

11 to 13 ____________________

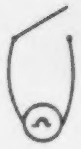
16 to 18 ____________________

PART IV

CHECKING UNITS WITH AN OHMMETER

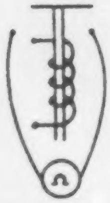
In the diagram below, write what the meter indication (∞ for no path I flow, 0 for path for I flow, 0+ for path for I flow with some R in it) would be if the units were good.

a.



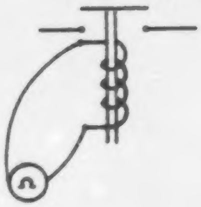
Reading_____

b.



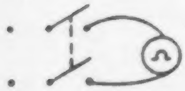
Reading_____

c.



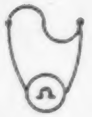
Reading_____

d.



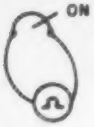
Reading_____

e.



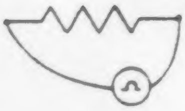
Reading_____

f.



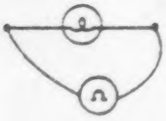
Reading_____

g.



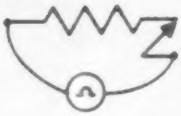
Reading_____

h.



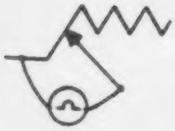
Reading_____

i.



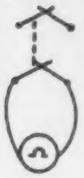
Reading_____

j.



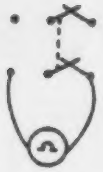
Reading________

k.



Reading________

l.



Reading________

PART V

CONSTRUCTING A SERIES CIRCUIT

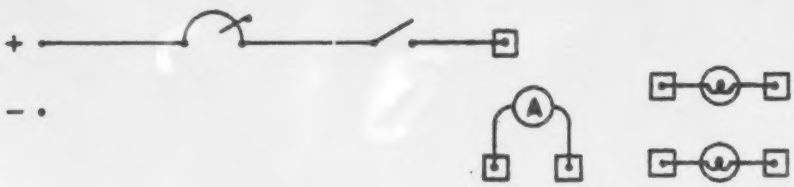
CAUTIONS

Remove jewelry.

Turn electrical power OFF before wiring circuits or removing units.

Be sure of correct multimeter setting before making measurements.

1. In the space below, the units to be included in the series circuit are a circuit breaker, an SPST switch, an ammeter, and two lamps. Use lines to represent the wires you will place on the trainer.



2. Have the instructor check your diagram.

3. Wire the circuit on the trainer using your diagram as a guide.

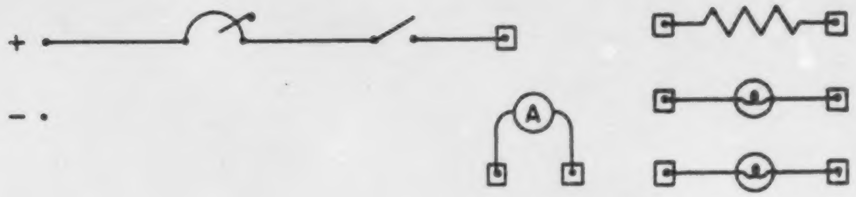
4. Have the instructor check your circuit.

NOTE: Circuit ammeter will be used to measure current. A multimeter will be used to measure voltage drops and applied voltage. Ohm's law will be used to determine resistance.

5. Turn the switch ON and complete the following for the circuit.

	LAMP 1	LAMP 2	TOTAL
E			
I			
R			

6. In the diagram below, use lines to represent how the fixed resistor would be wired in series to your circuit.



7. Have the instructor check your diagram.

8. Turn the switch ON and complete the following for the circuit.

	LAMP 1	LAMP 2	RESISTOR	TOTAL
E				
I				
R				

9. Remove the wires you placed on the trainer.

10. Complete the following statements.

a. A series circuit is a circuit with____________path for current flow.

b. The sum of the voltage drops should equal the______________voltage

c. Current is the______________throughout a series circuit.

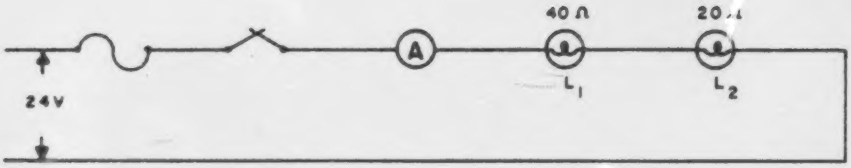
d. Total resistance may be found in a series circuit by______________the resistances of all units.

e. As units of resistance are added in a series circuit, will the current flow decrease, increase, or remain the same?________________

f. As units of resistance are added in a series circuit, will the total resistance decrease, increase, or remain the same?________________

11. **Solve the following circuit problems.**

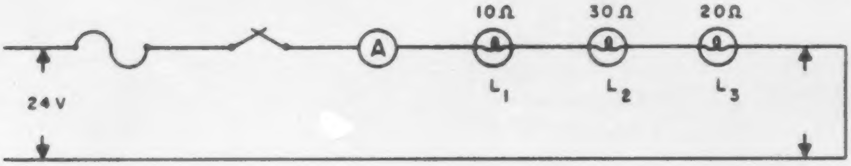
a. Problem No. 1.


40 Ω
20 Ω
A
L1
L2
24 V

Fill in the blanks below

	LAMP 1	LAMP 2	TOTAL
E			
I			
R	40	20	

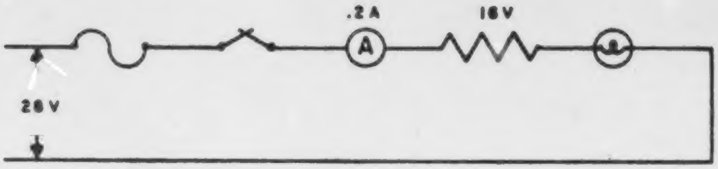
b. Problem No. 2.


10 Ω
30 Ω
20 Ω
A
L1
L2
L3
24 V

Fill in the blanks below

	LAMP 1	LAMP 2	LAMP 3	TOTAL
E				
I				
R	10	30	20	

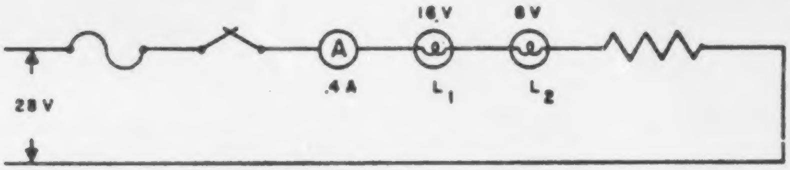
c. Problem No. 3.



Fill in the blanks below.

	LAMP	RESISTOR	TOTAL
E		16	28
I			.2A
R			

d. Problem No. 4.


16 V
8 V
A
.4 A
L_1
L_2
28 V

Fill in the blanks below.

LAMP 1	LAMP 2	RESISTOR	TOTAL

PART VI

CONSTRUCTING A PARALLEL CIRCUIT

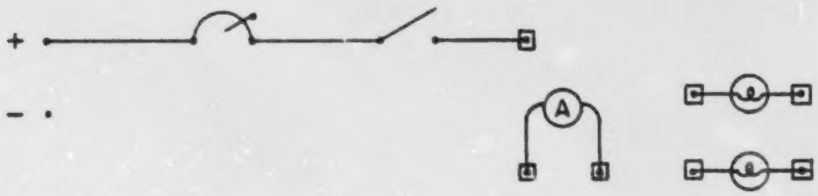
CAUTIONS

Remove jewelry.

Turn power OFF before wiring circuits or before removing and adding circuit components.

Be sure of correct multimeter setting before making measurements.

1. In the space below, the units to be included in the circuit are a circuit breaker, an SPT Switch, an ammeter to indicate total current flow, and two lamps in parallel. Use lines to represent the wires you will place on the trainer.



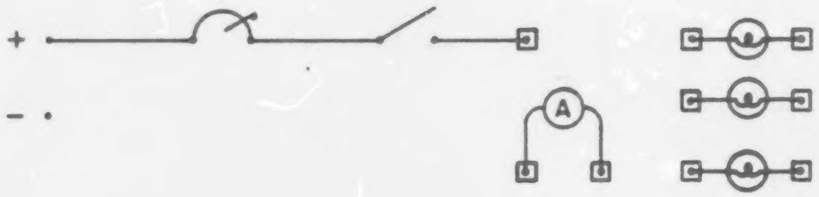
2. Have the instructor check your diagram.
3. Wire the circuit on the trainer using your diagram as a guide.
4. Have the instructor check your circuit.

NOTE: Circuit ammeter will be used to measure current. A multimeter will be used to measure voltage drops and applied voltage. Ohm's law will be used to determine resistance.

5. Turn the switch ON and complete the following for the circuit.

	LAMP 1	LAMP 2	TOTAL
E			
I			
R			

6. In the diagram below, use lines to represent **how a third light would be** wired in parallel to your circuit.



7. Have the instructor check **your diagram.**

8. Turn the switch ON and complete the following for the circuit.

	LAMP 1	LAMP 2	LAMP 3	TOTAL
E				
I				
R				

9. Remove the wires you place on the trainer.

10. Complete the following statements.

a. A parallel circuit is one with __________ or more paths for current flow.

b. The voltage drop of a unit in a parallel circuit should be equal to the __________________ voltage.

c. Total current is the __________ of the currents from each path in a parallel circuit.

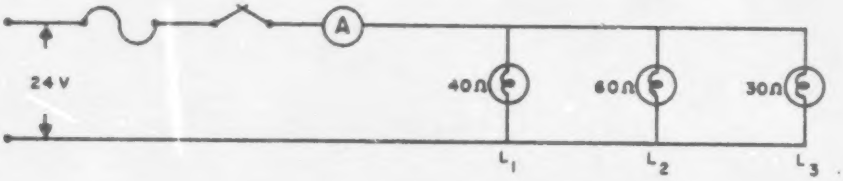
d. When additional units are added in parallel in a circuit, will the total resistance increase, decrease, or remain the same?

____

e. When units are added in parallel in a circuit, will the total current increase, decrease, or remain the same? ______________________________

11. Solve the following problems using Ohm's law.

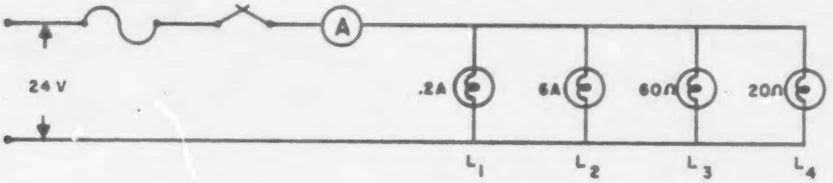
a. Problem No. 1.


A
24 V
40Ω
60Ω
30Ω
L1
L2
L3

Fill in the blanks below.

	LAMP 1	LAMP 2	LAMP 3	TOTAL
E				
I				
R				

b. Problem No. 2.

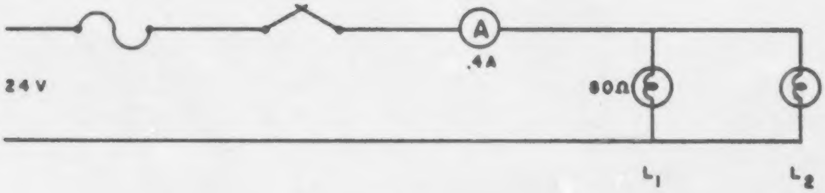

A
24 V
.2A
6A
60Ω
20Ω
L1
L2
L3
L4

Fill in the blanks below.

	LAMP 1	LAMP 2	LAMP 3	LAMP 4	TOTAL
E					
I					
R					

AF -75-658

c. Problem No. 3.


24 V
A
.4A
80Ω
L_1
L_2

Fill in the blanks below.

	LAMP 1	LAMP 2	TOTAL
E			
I			
R			

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR4550-2-I-2-P3

CIRCUIT ANALYSIS

OBJECTIVES:

Upon completion of this project you will be able to:

Diagnose and locate opens and shorts in an electrical circuit.

Identify the operating characteristics of ac circuits containing capacitors and inductors.

AR 75-658

Standard of performance

The standard of performance of this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-I-2-P3	1/student
Trainer, DC Troubleshooting	1/2 students
Pen or pencil	1/student

PROCEDURE

PART I

OPENS

1. When a wire is broken in a circuit, it is known as an ____________ circuit.

2. What is the indication of an open circuit? ____________________________

3. Meters that can be used to locate open circuits are:

   a. ____________________________

   b. ____________________________

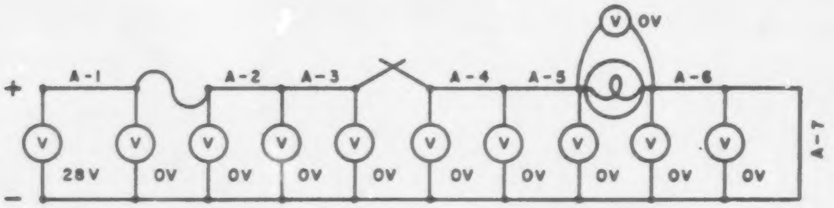
   c. ____________________________

Using a Voltmeter to Locate Opens

4. Study the diagrams below and list the location of the opens.

   NOTE: Wires are identified by code, A-1, A-2, etc.

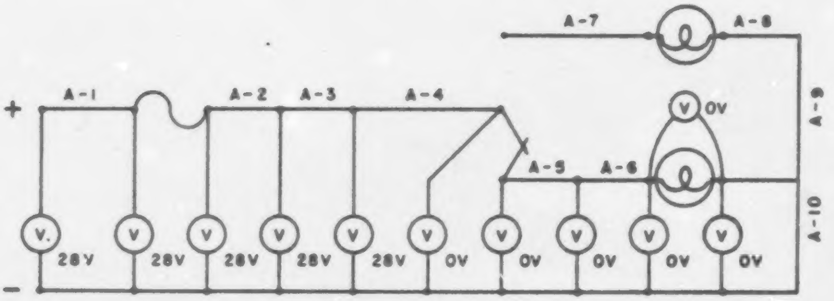
   a.



+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
V
0V
28V
0V
0V
0V
0V
0V
0V
0V
0V
0V

Location ____________________________

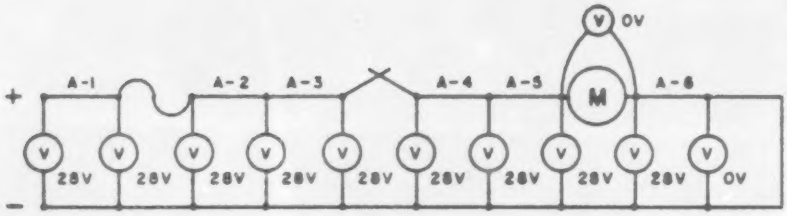
   b.



A-7
A-8
A-9
A-10
+
−
A-1
A-2
A-3
A-4
A-5
A-6
V
0V
28V
28V
28V
28V
28V
0V
0V
0V
0V
0V

Location ____________________________

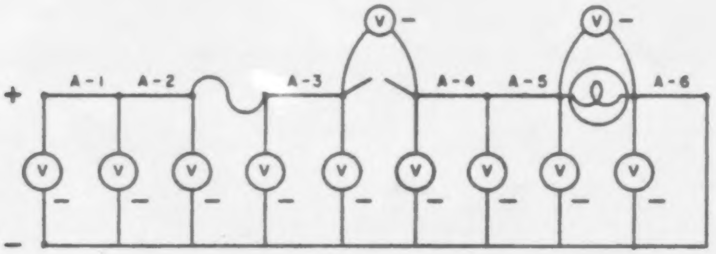
c.


V
0V
+
−
A-1
A-2
A-3
A-4
A-5
M
A-6
28V
28V
28V
28V
28V
28V
28V
28V
28V
0V

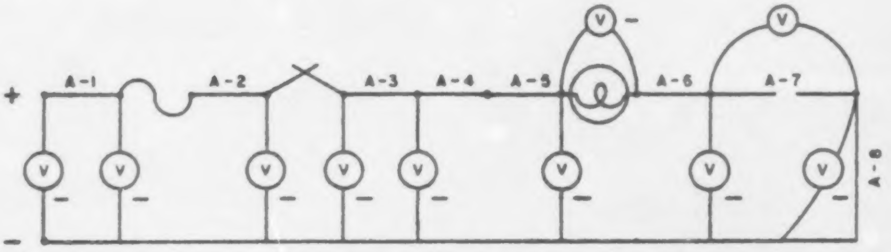
Location________________________________

5. Study the diagrams below and write the correct voltmeter readings by each voltmeter on the circuits to indicate the location of the opens. (Use 28 volts.)

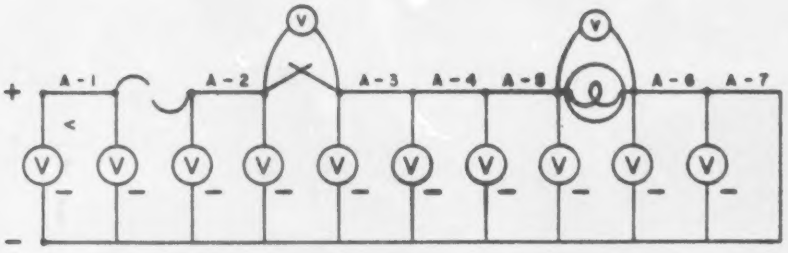
a. Location of open is switch.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
V
V
V
V
V
V
V
V
V
V
V

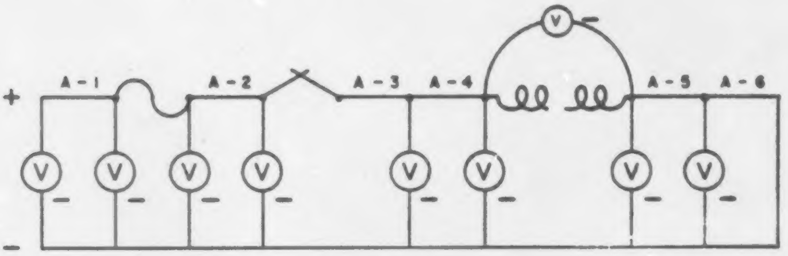
b. Location of open is A-7 wire.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
A-8
V
V
V
V
V
V
V
V
V
V
V

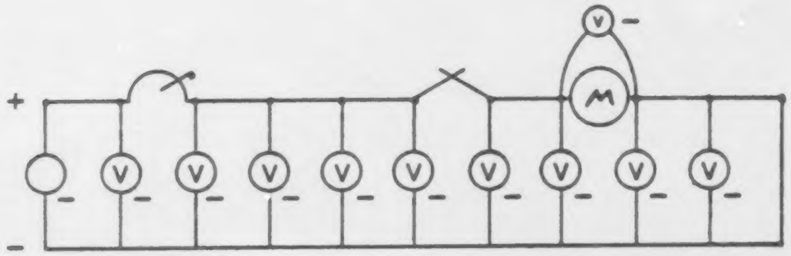
c. Location of open is fuse.


+
A - 1
A - 2
A - 3
A - 4
A - 5
A - 6
A - 7
V
–

d. Location of open is coil.

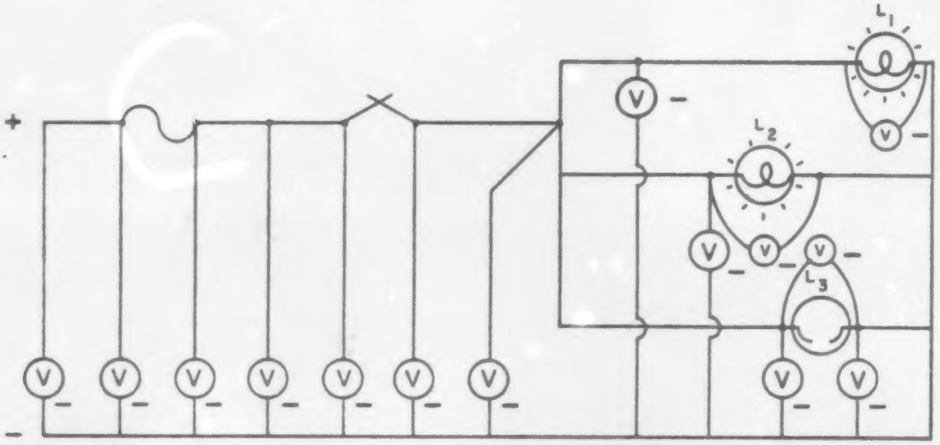

+
A - 1
A - 2
A - 3
A - 4
A - 5
A - 6
V
–

e. Location of open is motor.



162

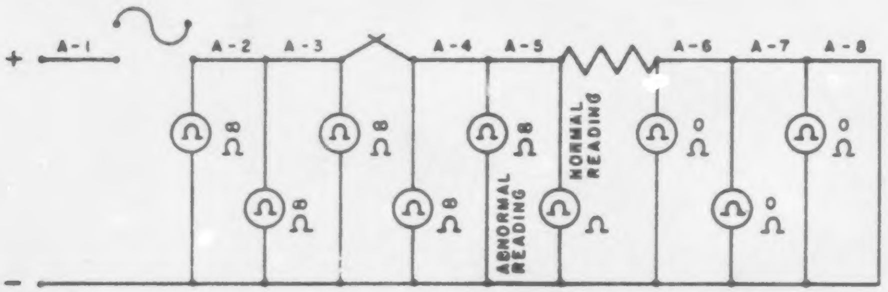
f. Location of open is L3.



Using the Ohmmeter to Locate Opens

6. Study the diagrams below and list the location of the opens.

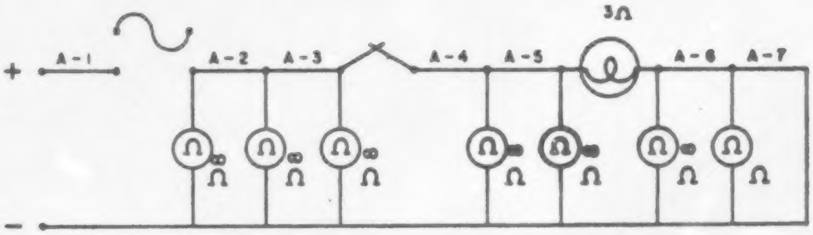
a.



+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
A-8
∞ Ω
0 Ω
Ω
ABNORMAL READING
NORMAL READING

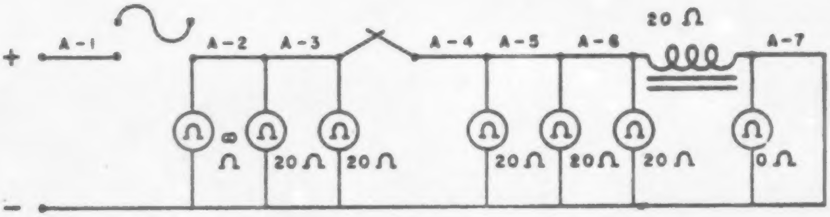
Location ______________________

b.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
3Ω
Ω ∞ Ω
Ω ∞ Ω
Ω ∞ Ω
Ω ∞ Ω
Ω ∞ Ω
Ω ∞ Ω
Ω Ω

Location______________________________

c.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
20 Ω
Ω ∞ Ω
Ω 20 Ω
Ω 20 Ω
Ω 20 Ω
Ω 20 Ω
Ω 20 Ω
Ω 0 Ω

Location______________________________

Shorts

1. When a positive wire is grounded and causes current to be returned in shortcuts to the source of power, it is known as a____________________________short.

2. A positive-to-positive short is called a______________________short when two independent circuits will operate from_____________________switch.

3. A circuit that causes a fuse to blow or a circuit breaker to trip has a trouble called a______________________short.

4. Meters that can be used to locate shorts are

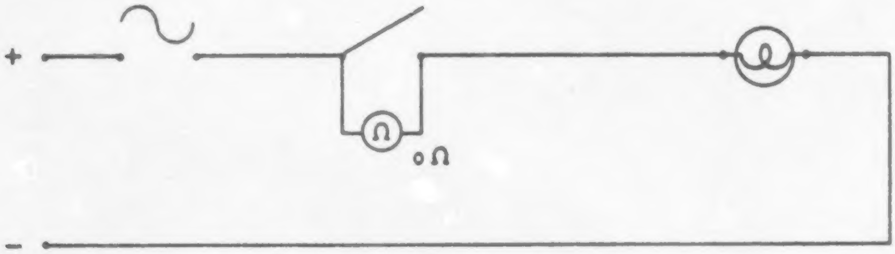
a. ________________________________

b. ________________________________

5. Always ____________________ a circuit before checking the circuit with an ohmmeter.

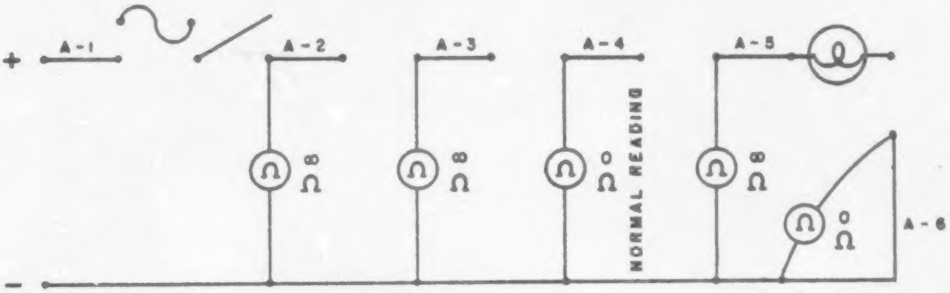
6. Study the diagram below. From the meter indication, the trouble is

____________________.

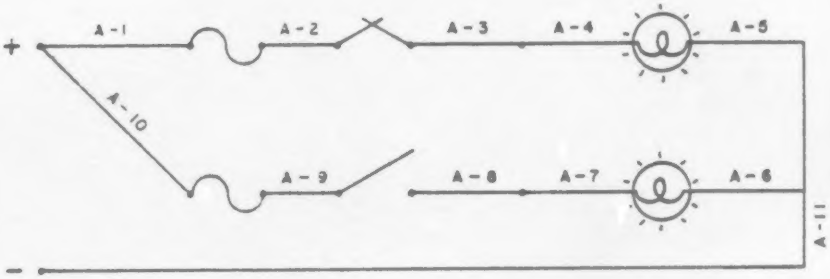


7. Study the diagram below. From the meter indications the trouble is a

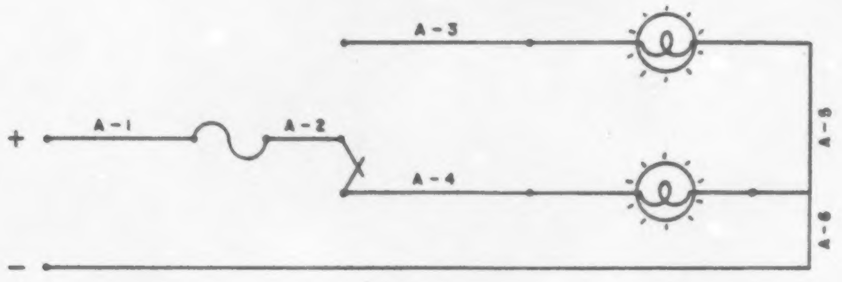
____________ short and its location is ________________________.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
∞ Ω
∞ Ω
0 Ω
NORMAL READING
∞ Ω
0 Ω

8. Study the diagram below. With your pencil, draw in a probable location of the short.


+
−
A-1
A-2
A-3
A-4
A-5
A-6
A-7
A-8
A-9
A-10
A-11

9. Study the diagram below. With your pencil, draw in a probable location of the short.



Trainer Use

INSTRUCTIONS:

Locate and diagnose the troubles caused by each of the trouble switches listed on the fill-in chart below.

Circuit Trouble Analysis

NOTE: On the trainer assigned to you, be sure all the trouble switches to your left are OFF. Operate all circuits. No troubles should exist. Now you are ready to troubleshoot. Begin by turning trouble switch No. 1 ON. Operate all circuits and determine the defective circuit. Fill in the blanks below.

TROUBLE SWITCH	DEFECTIVE CIRCUIT OR CIRCUITS (List letter of circuit, A-E)	TYPE OF TROUBLE	LOCATION
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

Checked by___________________________
Instructor

PART II

INSTRUCTIONS:

Fill in the blanks below.

AC Operating Characteristics

1. A________________________causes inductive reactance in an ac circuit.

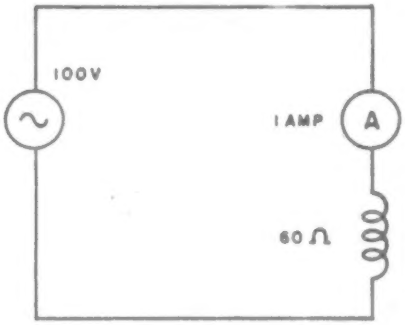
2. ________________________causes current to lag voltage in an ac circuit.

3. Draw the symbol for a coil.

4. Using a red pencil to represent voltage, and a blue pencil to represent current, show the relationship of current and voltage in an inductive circuit.

5. What is the letter symbol for inductive reactance?________________________

6. What is the opposition offered by the inductor in the circuit shown called?



a. Total opposition is__________ohms.

b. Resistance (measured) of the coil is__________________ohms.

7. A__________________causes capacitive reactance in an ac circuit.

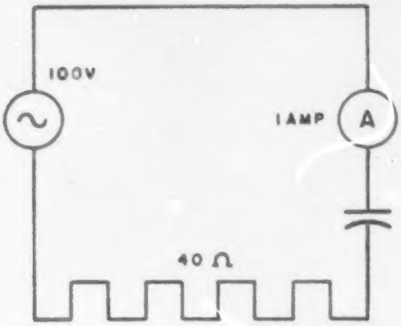
8. ___________________causes current to lead voltage in an ac circuit.

9. Draw the symbol for a capacitor.

10. Using a red pencil to represent voltage, and a blue pencil to represent current, show the relationship of current and voltage in a capacitive circuit.

11. What is the letter symbol for capacitive reactance?________________________

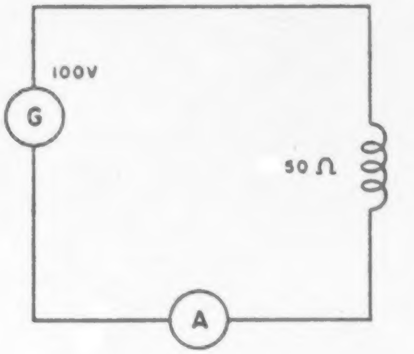
12. What is the opposition offered by the capacitor in the circuit shown called?



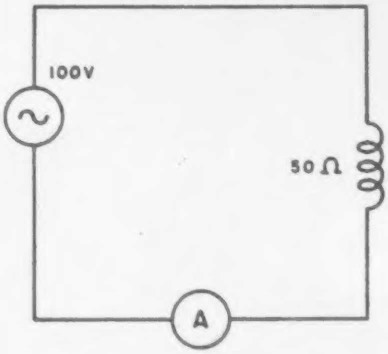
a. Total opposition is__________ohms.

b. Resistance (measured) of the heater is________________ohms.

13. What is the current flow in the "A" circuit shown below.



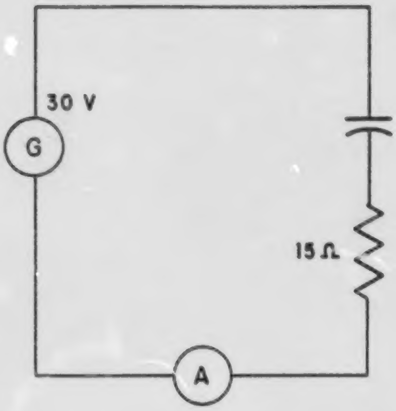
"A" CIRCUIT

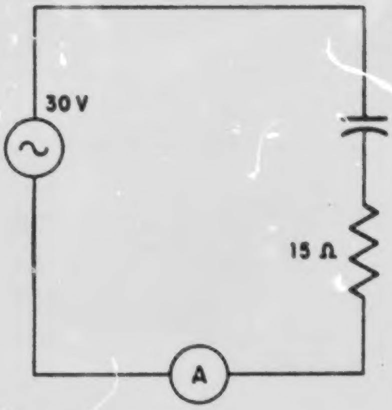


"B" CIRCUIT

14. Will the current flow in "B" circuit (above) be less than, more than or equal to the current flow in problem 13?____________________

15. The ammeter will indicate____________amps for the circuit shown below at the left.





16. Will the current flow in the circuit on the right be more than, less than, or equal to, the current flow in problem 15?________________________

Checked by________________________
Instructor

READING MOTOR DATA PLATE, MOTOR CONSTRUCTION AND WIRING

OBJECTIVES:

Upon completion of this project you will be able to:

Wire a 110-volt, single-phase circuit to a single-phase power source.

Wire a 220-volt, single-phase circuit to a single-phase power source.

Wire a 220-volt, three-phase circuit to a three-phase power source

Identify the major components of single-phase and three-phase motors.

Wire single-phase and three-phase motors according to data plate requirements.

Read and correctly interpret the data on a motor data plate.

Standard of performance:

The standard of performance of this project is 100 percent completion errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-I-2-P4	1/student
Trainer, Component Wiring	1/12 students
Pen or pencil	1/student

PROCEDURE

PART I

READING A MOTOR DATA PLATE

Using the data plate illustrated below, enter the information in the following blank spaces to adequately identify motor installation and operation data.

1. Manufacturer's Name____________________
2. Horsepower Rating____________________
3. Temperature Rise - 50 cycles__________ 60 cycles__________
4. RPM at full load - 50 cycles __________ 60 cycles__________
5. Frequency____________________
6. Number of phases____________________
7. Voltages motor will operate on____________________
8. Full load current on high voltage - 50 cycles____________________

   60 cycles____________________
9. Frame Number____________________ and design/code_______/_______

General Electric - Induction Motor			
HP 2	Ph 3	Cy 50	60
Volts 208/220/440		RPM 950	1145
Frame 184	Hi Volt Amps 3.6 - 3.1		
Type K	Low Volt Amps 7.2 - 6.2		
Design B Code L	Rating 50°C - 40°C		
	SF 1.	SF 1.25	

Motor Data Plate

WIRING 1 Ø INDUCTION MOTORS

1. Using the data plate information and symbols available in the diagram below connect the motor to the power supply using the across-the-line motor starter and thermostat to control the operation of the motor.

2. Connect the motor to rotate clockwise.

3. Use red pencil to draw load circuit and blue pencil to draw the control circuit.

4. What size heater will be used for the motor? ______________________________
(Use chart below to select heater size)

5. How many hot leads are needed to operate the motor? ______________________

6. What size wire should be used? ______________________________________
Use wire size selection chart below.

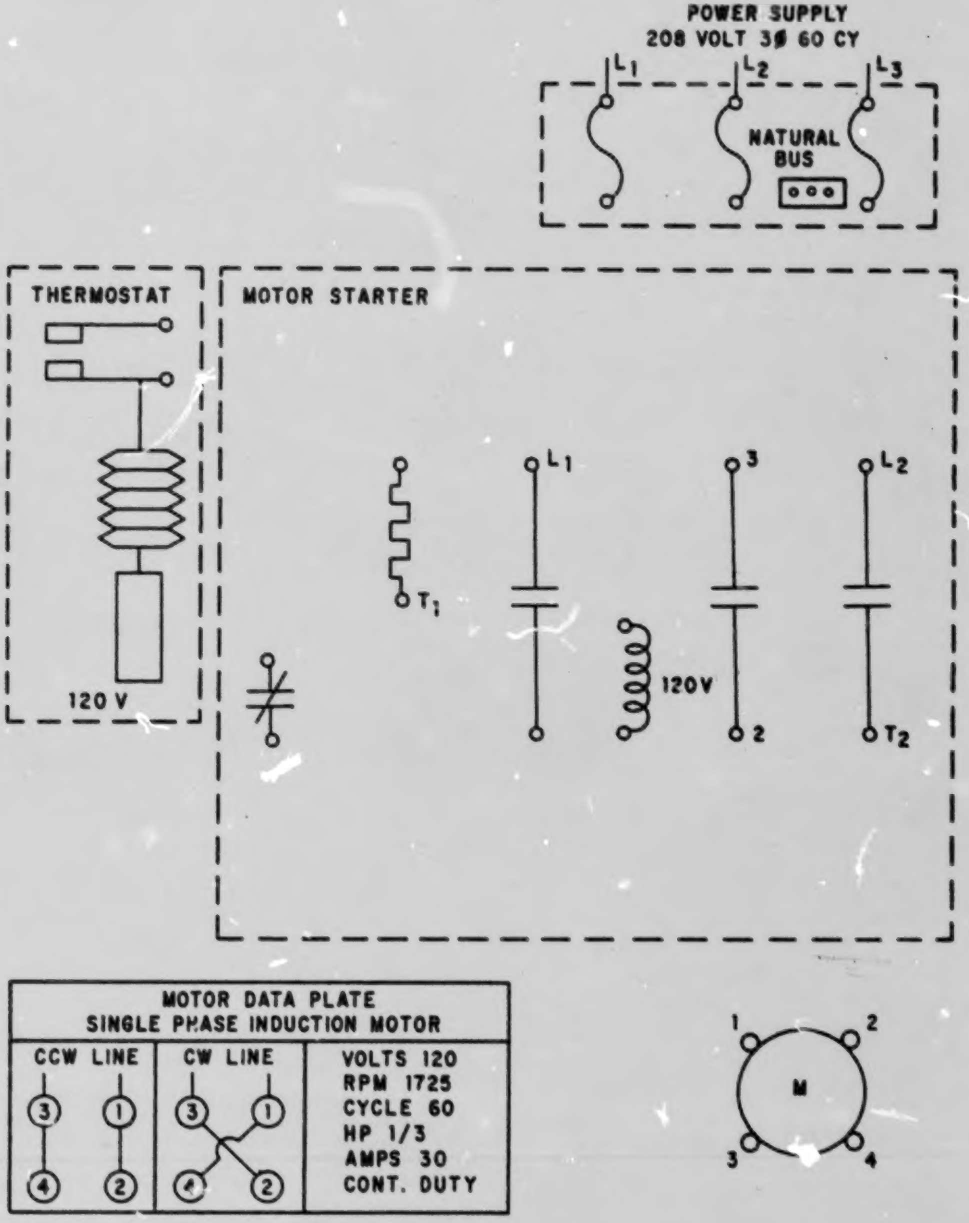
7. The coil is connected in what circuit? ________________________________

Heater Selection Chart

Heater No.	F. L. Amps	Heater No.	F. L. Amps	Heater No.	F. L. Amps
1	.2 - .8	6	3.5 - 3.9	11	7.4 - 7.9
2	.9 - 1.4	7	4.0 - 4.6	12	8.0 - 8.6
3	1.5 - 2.0	8	4.7 - 5.5	13	8.7 - 9.3
4	2.1 - 2.7	9	5.6 - 6.3	14	9.4 - 9.7
5	2.8 - 3.4	10	6.4 - 7.3	15	9.8 - 10.0

Wire Size Selection Chart

Conductor Size AWG	Maximum Current Capacity (for Rubber Insulation
16	6
14	15
12	20
10	25
8	35
6	50
4	70
2	90


POWER SUPPLY
208 VOLT 3∅ 60 CY
L1
L2
L3
NATURAL BUS
THERMOSTAT
120 V
MOTOR STARTER
T1
L1
3
L2
120V
2
T2
MOTOR DATA PLATE
SINGLE PHASE INDUCTION MOTOR
CCW LINE
CW LINE
3
1
4
2
VOLTS 120
RPM 1725
CYCLE 60
HP 1/3
AMPS 30
CONT. DUTY
M
1
2
3
4

WIRING 3 ∅ INDUCTION MOTOR

1. Using the information and symbols shown, connect the motor to the power supply using the across-the-line motor starter and thermostat to control the operation of the motor.

2. Use red pencil to draw load circuit and blue pencil to draw the control circuit.

3. What size heater will be used for the motor? ______________________
(Use chart shown below.)

4. How many hot leads are needed to operate the motor? ______________________

____

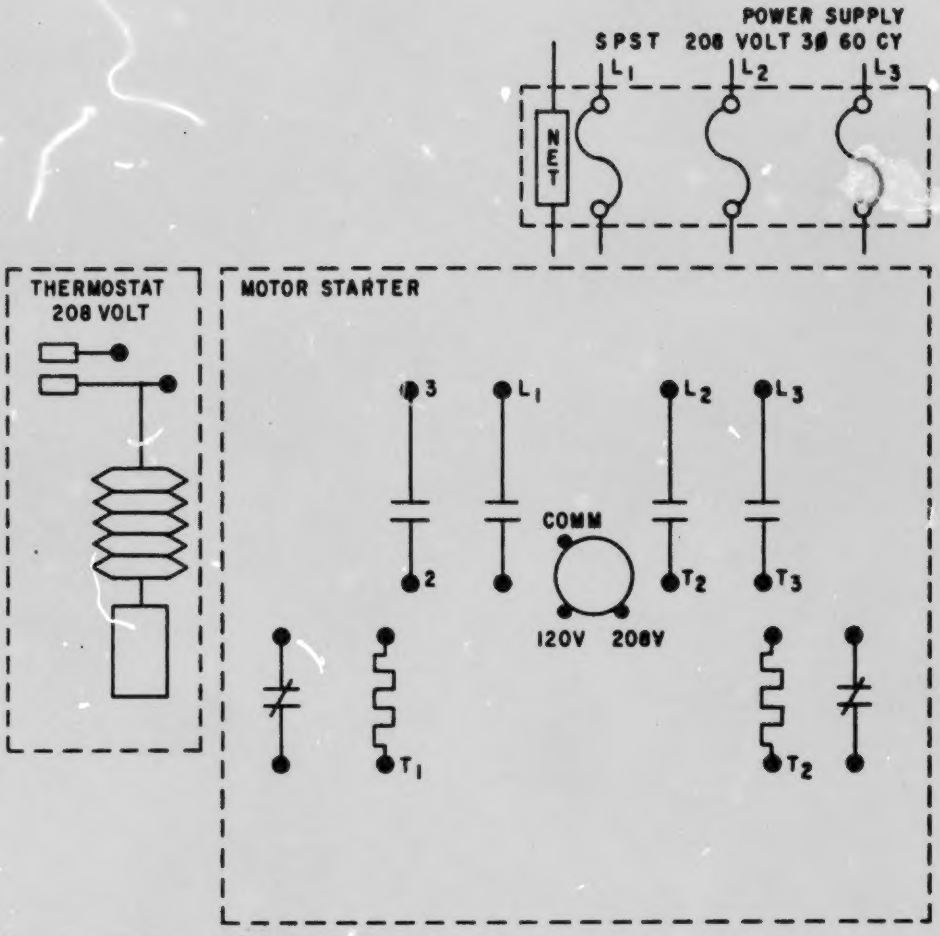
5. The coil is connected in what circuit? ______________________

6. The direction of rotation can be changed by changing what terminal leads?

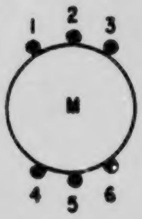
____

Heater Selection Chart

Heater No.	F. L. Amps	Heater No.	F. L. Amps	Heater No.	F. L. Amps
1	.2 - .8	6	3.5 - 3.9	11	7.4 - 7.9
2	.9 - 1.4	7	4.0 - 4.6	12	8.0 - 8.6
3	1.5 - 2.0	8	4.7 - 5.5	13	8.7 - 9.3
4	2.1 - 2.7	9	5.6 - 6.3	14	9.4 - 9.7
5	2.8 - 3.4	10	6.4 - 7.3	15	9.8 - 10.0


POWER SUPPLY
SPST
208 VOLT 3ø 60 CY
L_1
L_2
L_3
NET
THERMOSTAT
208 VOLT
MOTOR STARTER
3
L_1
L_2
L_3
COMM
2
T_2
T_3
120V
208V
T_1
T_2

DATA PLATE MOTOR THREE PHASE			
VOLTAGE	208	440	CYCLE 50/60 PPM 1425/1725 CONT. DUTY HP 1/4
AMPS	1.1	.55	
WIRING	① ② ③ ⑥ ④ ⑤	① ② ③ ⑥-④-⑤	



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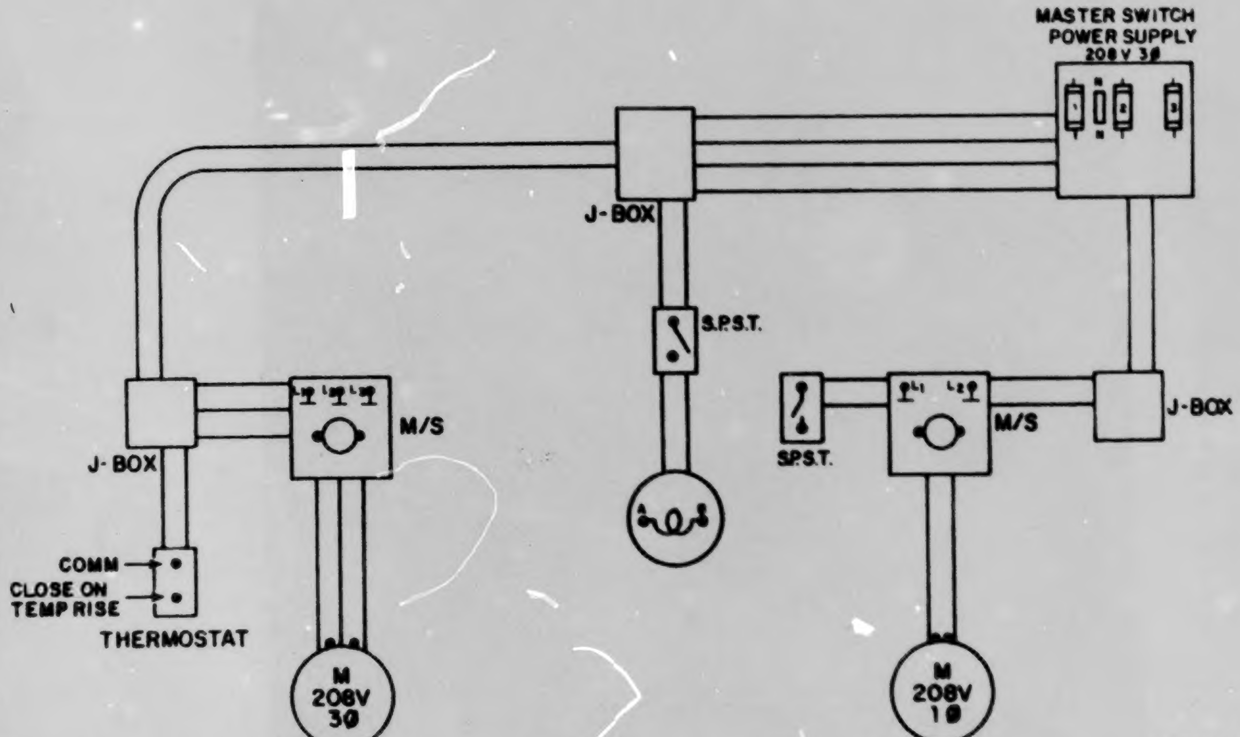
PART II

WIRING TO POWER SUPPLIES

INSTRUCTIONS:

Refer to the diagram and listed procedures shown below as you wire the electrical systems.

CAUTION: Be sure the trainer is disconnected from the electrical power supply. All jewelry will be removed prior to starting this project. Rubber mats will be placed around the trainer and will be used.


MASTER SWITCH
POWER SUPPLY
208 V 3Ø
1
N
2
3
J-BOX
S.P.S.T.
J-BOX
M/S
L1
L2
S.P.S.T.
M
208V
1Ø
J-BOX
M/S
L1
L2
L3
COMM
CLOSE ON
TEMP RISE
THERMOSTAT
M
208V
3Ø

CME-032

1. Locate and remove cover from 30 motor starter.

2. Locate and remove cover from switching device.

3. Install 2 wires through conduit, between motor starter and switching device.

4. Strip one-fourth inch insulation from wire at motor starter and connect this end to motor starter at power source above stationary contacts on line side.

5. Check thermostat terminals with an ohmmeter to determine what terminals are closed on a rise in temperature.

6. Strip one-half inch of insulation from wires at thermostat and connect them to the two terminals identified in step 5.

7. Connect second wire from thermostat to right terminal of holding coil on motor starter.

8. Check all new connections to ground with an ohmmeter to insure no grounding of circuits.

9. Check the control circuit of the three-phase motor starter with an ohmmeter to insure it is complete and correct.

10. Locate and remove cover from single-phase motor starter.

11. Remove cover and SPST switch from switch box.

12. Install 2 wires in conduit between 10 motor starter and SPST SW.

13. Strip one-fourth insulation from wires on motor starter end and one-half inch from SPST switch end.

14. Make connection for one wire on line side of motor starter for a power source.

15. Connect opposite end of wire used in step 14 to top side of SPST SW.

16. Connect second wire to bottom side of SPST SW.

17. Reinstall switch and cover plate.

18. Connect opposite end of wire from bottom of SPST switch to right terminal of holding coil.

19. Check all connections with an ohmmeter to insure no grounding of circuits.

20. Trace circuits with ohmmeter to insure their completion.

21. Have instructor check your work.

CAUTION: Do not plug trainers into the power **supply until** instructed to do so by the instructor.

22. When directed by the instructor, plug in trainer and turn on power.

23. Check all circuits by energizing control **circuits** for operation of motors.

24. Check power supply in main power supply box (TPST SW) with voltmeter set in the 400V ac range. Record readings in blanks provided below:

fuses 1 to 2____________fuses 2 to 3____________**fuses** 1 to 3____________

25. Check power supply at line side of 3Ø motor starter using voltmeter on 400V ac and record readings in blanks provided:

line 1 to 2____________line 2 to 3____________line 1 to 3____________

26. Check power supply at line side of 1Ø motor starter using voltmeter on 400V ac and record readings in blanks provided:

line 1 to 2_______________L1 to N in main power box_____________________

L2 to N in main power box_________________.

27. Turn off control circuits, main power, and unplug trainer.

28. Remove all wiring from the trainer that you have installed.

29. Replace tools to proper storage area and clean your area by placing wire in scrap wire container, replacing rubber mat and sweeping your trainer area.

TE 75-658

PART III

SINGLE-PHASE MOTOR CONSTRUCTION AND INTERNAL WIRING

1. The illustrations below are the major parts of a single-phase motor. In the blank space provided, write the name of the appropriate component.

A ______________________________

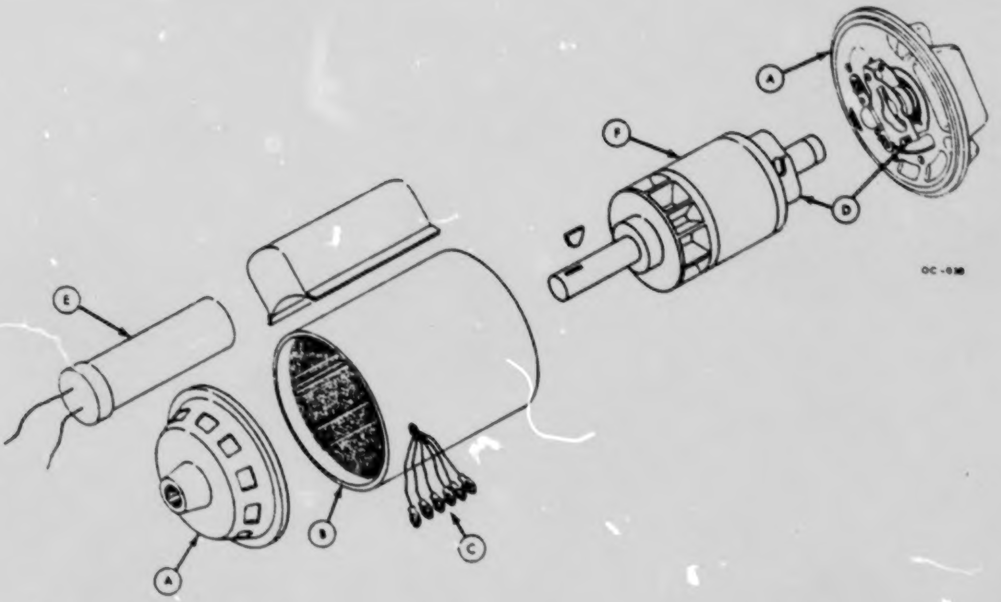
B ______________________________

C ______________________________

D ______________________________

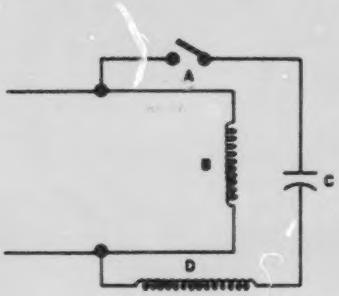
E ______________________________

F ______________________________

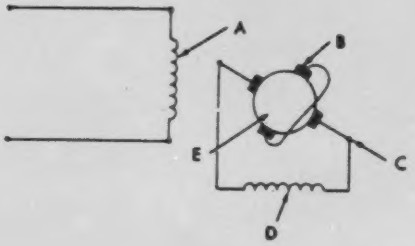


Major Parts of a Single-Phase Motor

2. Write the name of each major component where a letter appears. In the spaces provided under each drawing, correctly identify the type of motor shown.



DO-081A



DO-093

3. The left diagram is the schematic of a ______________________________ motor.

4. The right diagram is the schematic of a ______________________________ motor.

5. Major components of the (left) circuit are:

a. ______________________________

b. ______________________________

c. ______________________________

d. ______________________________

Major components of the (right) circuit are:

a. ______________________________

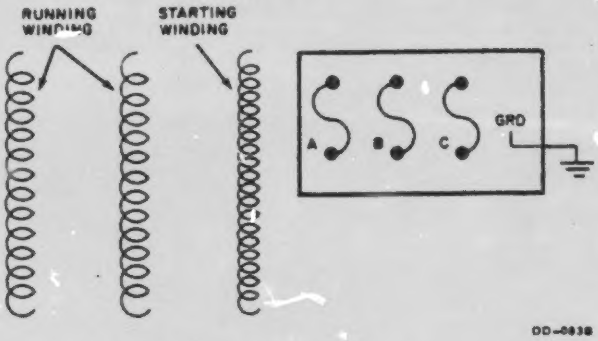
b. ______________________________

c. ______________________________

d. ______________________________

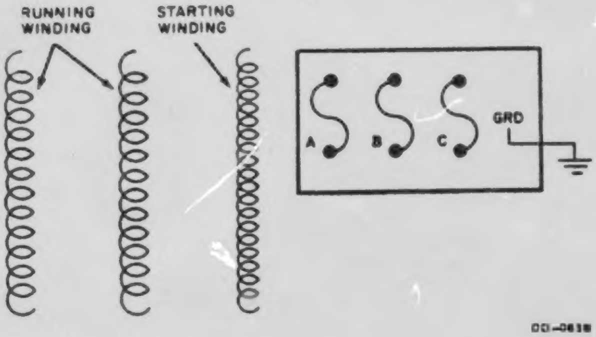
e. ______________________________

6. Complete the diagram below by numbering the motor windings and drawing in the necessary connections for 220-volt operation.


RUNNING WINDING
STARTING WINDING
A
B
C
GRD
DD-0838

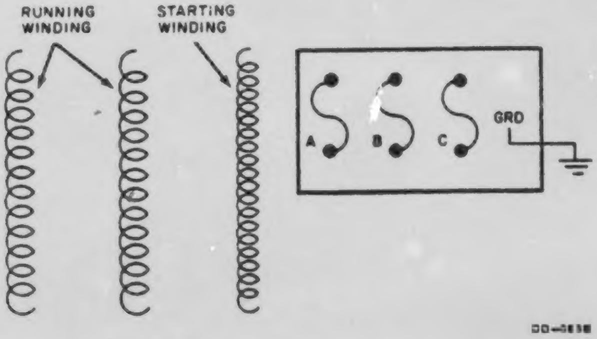
Single-Phase Motor Winding

7. Complete the diagram below by numbering the motor windings and drawing in the necessary connections for 110-volt operation.


RUNNING WINDING
STARTING WINDING
A
B
C
GRD
DD-0838

Single-Phase Motor Winding

8. Reverse direction of rotation of this motor compared to the motor above. Connect for low voltage.


RUNNING WINDING
STARTING WINDING
A
B
C
GRD
DD-0838

Single-Phase Motor Winding

Three-Phase Motor Construction and Internal Wiring

1. Illustrated below is a picture of a three-phase motor. Identify these parts by writing the name of each part in the space provided.

A ______________________

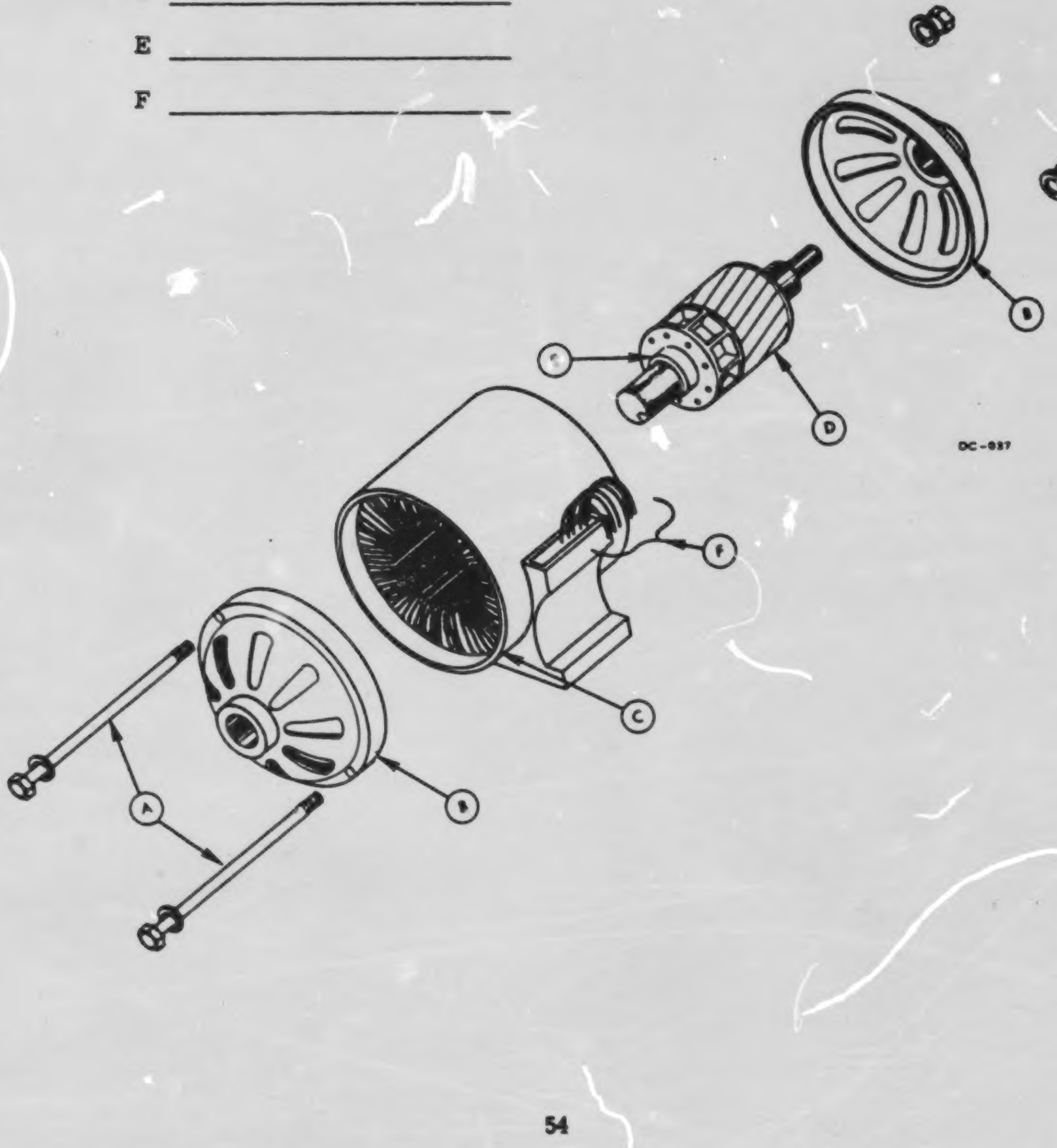
B ______________________

C ______________________

D ______________________

E ______________________

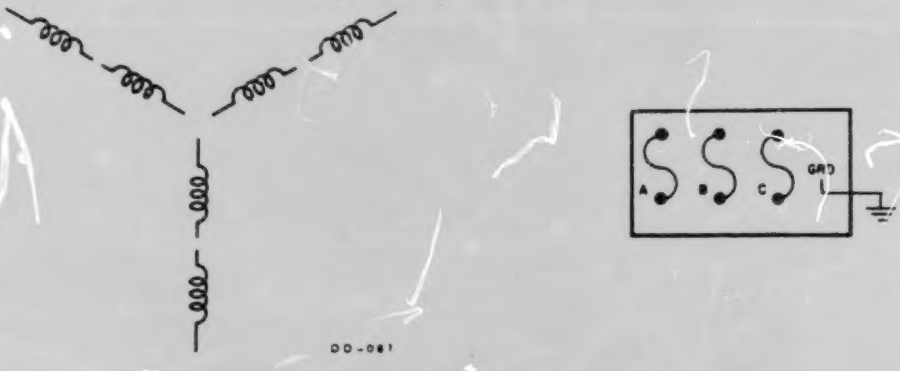
F ______________________



2. Match the correct terms on the left with the statements on the right by writing the number in the space provided:

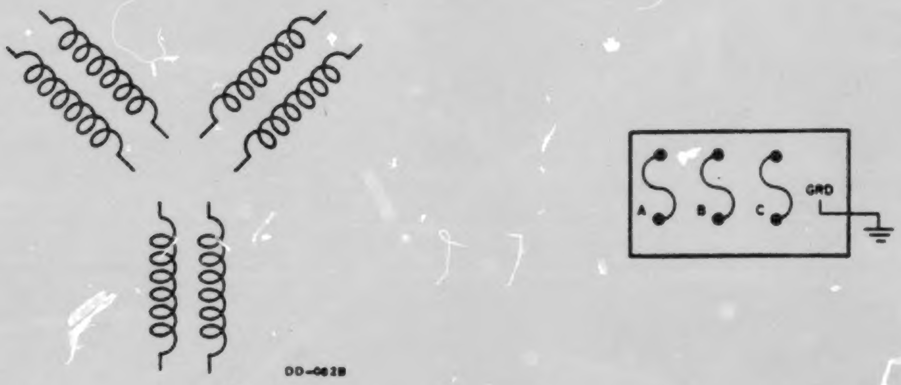
1.	Rotor	______	Supports the rotor, houses the bearings and completes the frame
2.	Endbells	______	Allow the rotor to turn smoothly
3.	Stator	______	Moving part of this particular motor
4.	Bearing	______	That part of the rotor that may be a connection point for the load
5.	Shaft	______	Holds the field winding and core
6.	Field Winding	______	That which develops a rotating magnetic field
7.	Fan	______	Reduces and eliminates heat from around the inside of the motor

3. Complete the schematic diagram below by numbering the motor windings and drawing in the necessary connections and conductors for applying 440-volt power to the motor for high-voltage operation.



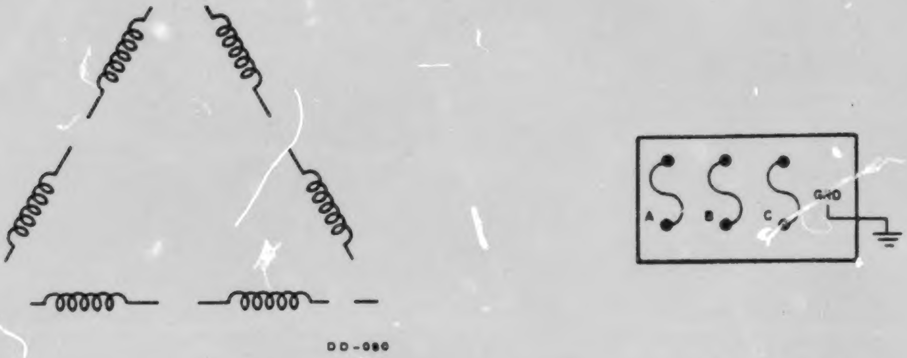
440-Volt Circuit Diagram

4. Complete the schematic diagram below by numbering the motor windings and drawing in the necessary connections and conductors for applying 220-volt power to the motor for low voltage.



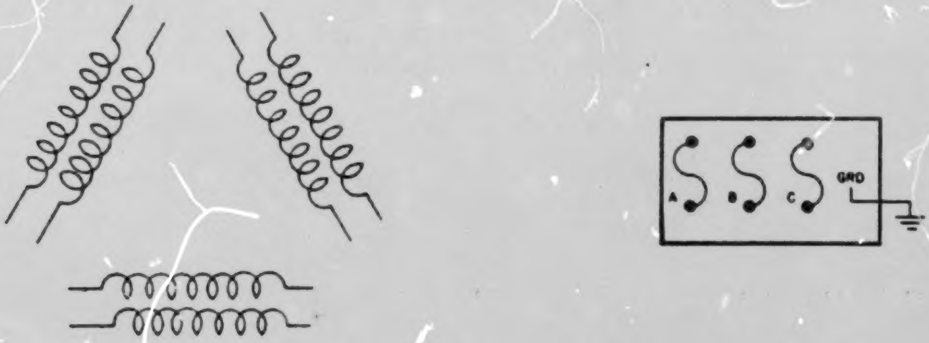
220-Volt Circuit Diagram

5. Complete the schematic diagram below by numbering the motor windings and drawing in the necessary connections and conductors for applying 440-volt power to the motor for high voltage.



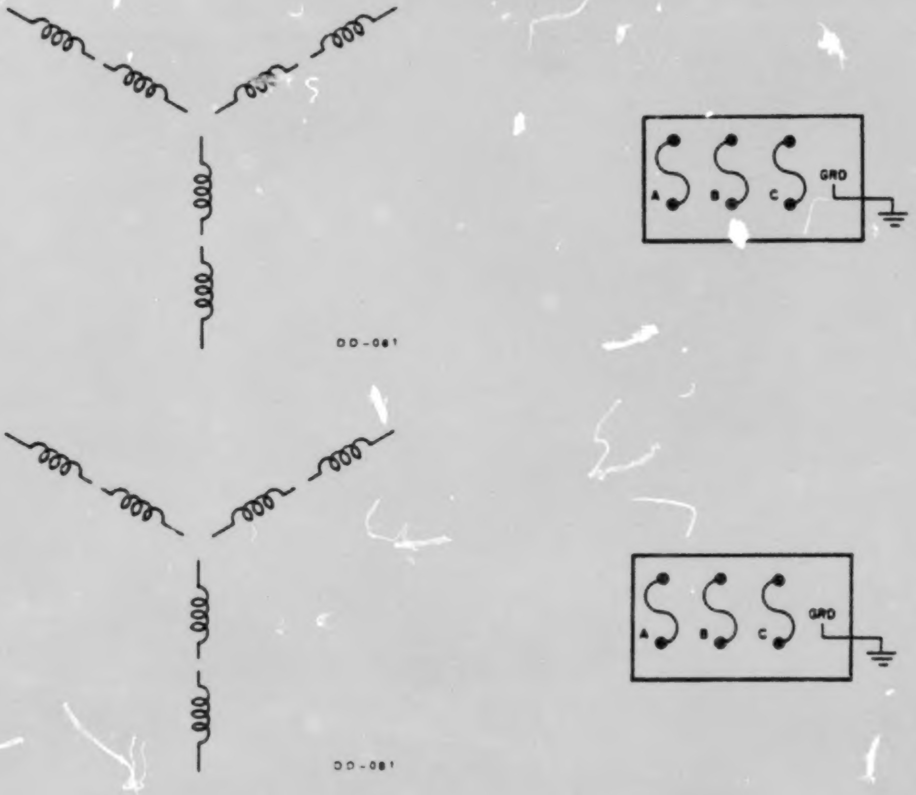
440-Volt Circuit Diagram

6. Complete the schematic diagram below by numbering the motor windings and drawing in the necessary connections and conductors for applying 220-volt power to the motor for low voltage.



220-Volt Circuit Diagram

7. Show connections for reversing the direction of rotation by numbering the motor windings and drawing in the necessary connections for a wye connected high-voltage system.



Forward or Reverse Diagrams

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Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-I-2-P5

TROUBLESHOOTING AC CIRCUITS

OBJECTIVES:

Upon completion of this project you will be able to:

Use multimeter to troubleshoot the malfunctions of the 120-volt, single-phase trainer.

Use multimeter to troubleshoot the malfunctions of the 220-volt, single-phase trainer.

Use multimeter to troubleshoot the malfunctions of the 220-volt, three-phase trainer.

Standard of performance

The standard of performance of this project is 100 percent completion errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-I-2-P5	1/student
Trainer, AC Troubleshooting	1/12 students
Pen or pencil	1/student

PROCEDURE

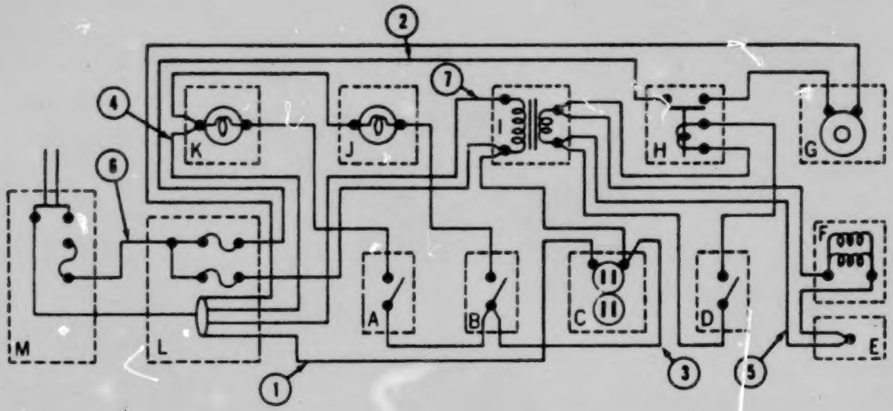
RF -75-658

PART I

TROUBLESHOOTING A 120-VOLT ELECTRICAL SYSTEM

Analyzing Electrical Circuits Using a Diagram

The wires on the diagram below have been numbered 1 through 7. By each numbered wire below, list the unit by letter that would be inoperative if that specific wire were open. (Study the diagram carefully.)



Wire Number	INOPERATIVE UNITS
1	
2	
3	
4	
5	
6	
7	

Determining Location of Troubles by Use of Meters

1. Note that the diagram you have been studying is also the diagram of the trainer assigned to you by the instructor.

NOTE: Use only the top half, 120-volt part, of the trainer.

2. Be sure that all control devices are in the OFF position.

3. Be sure that the trouble switches at the right end of the trainer are in the OFF position.

4. Connect the trainer to the wall receptacle.

5. Turn the switch box at the end of the trainer ON.

6. Turn the 120V switchbox ON.

7. Make an operational check of all the units.

NOTE: If there is a malfunction in the trainer, report it to the instructor.

8. Obtain a multimeter to be used in locating the trouble.

9. Start your troubleshooting by turning trouble switch No. 1 (on the right end of the trainer) ON.

10. Operate all circuits to determine the defective circuit.

a. What is the type of trouble?____________________________

b. Where is it located?____________________________

c. What meter did you use to find its location?____________________________

11. Turn No. 1 OFF. Turn No. 2 ON. Operate all circuits. Proceed with your troubleshooting. Fill in the blanks on the opposite page.

TROUBLE SWITCH	Type of TROUBLE	LOCATION	METER USED
2			
3			
4			
5			
6			

12. Turn all switches OFF and disconnect trainer from wall receptacle.

Checked by____________________ _____
Instructor

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PART II

TROUBLESHOOTING A 208-VOLT, SINGLE-PHASE ELECTRICAL SYSTEM

Analyzing Electrical Circuits Using a Diagram

The wires on the diagram below have been numbered 1 through 12. By each numbered wire in the spaces below, list the unit or units by letter that would be inoperative if that specific wire were open. (Study the diagram carefully.)

WIRE NO	INOPERATIVE UNITS
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

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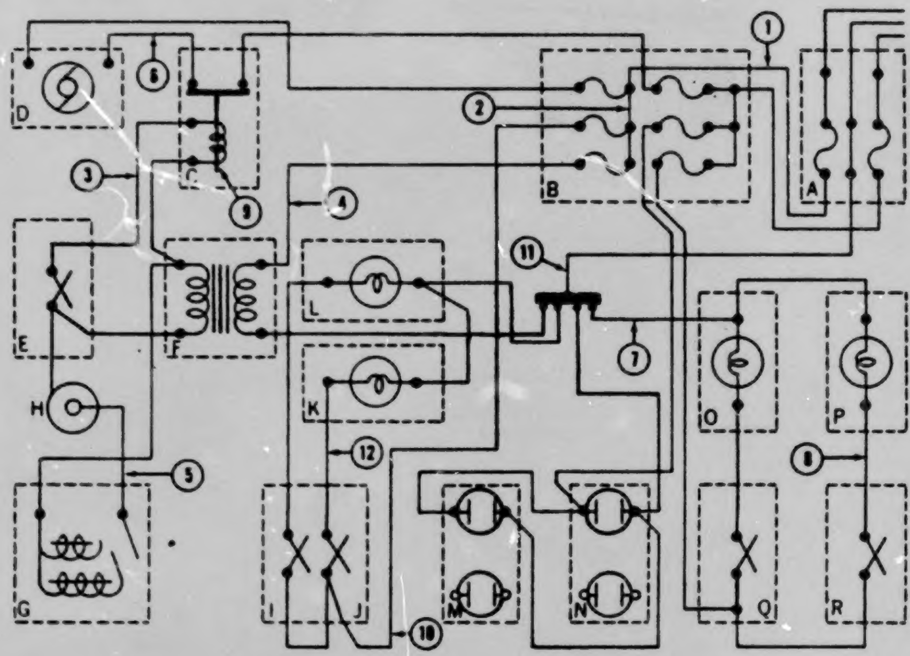

1
2
3
4
5
6
7
8
9
10
11
12
A
B
C
D
E
F
G
H
I
J
K
L
M
N
O
P
Q
R

208-V, 60-Cycle, Single-Phase Circuit

Determining Location of Troubles by Use of Meters

1. Note that the diagram you have been studying is also the diagram of the trainer assigned to you by the instructor.

   NOTE: Use only the 208-V, single-phase part of the trainer

2. Be sure all control devices are in the OFF position.

3. Be sure all the trouble switches at the right end of the trainers are in the OFF position.

4. Connect the trainer to the wall receptacle.

5. Turn the switch box at the end of the trainer ON.

6. Turn the 208-V, single-phase, switchbox ON.

7. Make an operational check of all the units.

   NOTE: If there is a malfunction in the trainer, report it to the instructor.

8. Obtain a multimeter to be used in locating the troubles.

9. Start your troubleshooting by turning trouble switch No. 2 (on the right end of the trainer) ON.

10. Operate all circuits to determine the defective circuit.

    a. What is the type of trouble?______________________________

    b. Where is it located?___________________________________

    c. What meter did you use to find its location?____________________

11. Turn No. 2 OFF. Turn No. 3 ON. Operate all circuits. Proceed with your troubleshooting. Fill in the blanks below.

TROUBLE SWITCH	TYPE OF TROUBLE	LOCATION	METER USED
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

12. Turn all switches OFF and disconnect trainer from wall receptacle.

Checked by________________________
Instructor

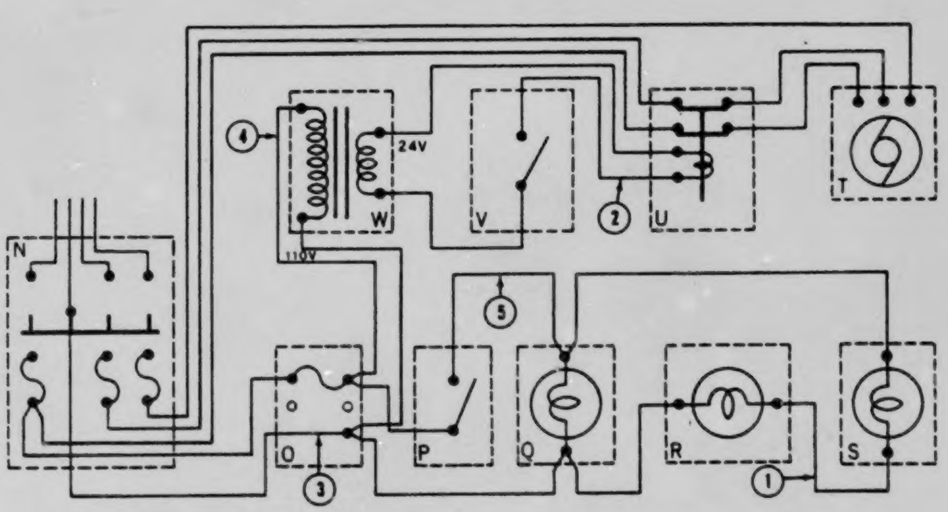
PART III

TROUBLESHOOTING A 208-VOLT, THREE-PHASE, ELECTRICAL SYSTEM

Analyzing Electrical Circuits Using a Diagram and Meters

1. The wires on the diagram below have been numbered 1 through 5. Beside each wire number in the spaces below, list the unit by letter that would be inoperative if that specific wire were open.

WIRE NUMBER	INOPERATIVE UNITS
1	
2	
3	
4	
5	



2. Note that the diagram you have been studying is that of the trainer assigned to you by the instructor.

3. Be sure all control devices are in the OFF position.

4. Be sure all trouble switches at the right end of the trainer are in the OFF position.

5. Connect the trainer to the wall receptacle.

6. Turn the switchbox at the end of the trainer ON.

7. Turn the 208-V switchbox ON. (Only the bottom half of the trainer 208-V part, is to be used.)

8. Make an operational check of all the units. If there is a malfunction in the trainer, report it to the instructor.

9. Obtain a multimeter to be used in locating the troubles.

10. Start your troubleshooting by turning trouble switch No. 7 (on the right end of the trainer) ON. Operate all circuits to determine the defective circuit.

a. What is the type of trouble? ____________________

b. Where is it located? ____________________

c. What meter did you use to find its location? ____________________

11. Turn switch No. 7 OFF. Turn switch No. 8 ON. Operate all circuits. Proceed with your troubleshooting. Fill in the blanks.

TROUBLE SWITCH	TYPES OF TROUBLE	LOCATION	METER USED
8			
9			
10			
11			
12			

12. Turn all switches OFF and disconnect the trainer from the wall receptacle.

Checked by____________________ ____
Instructor

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WB 3AZR54550-2-I-3-P1

MAJOR COMPONENTS AND REFRIGERANT FLOW THROUGH A SYSTEM

OBJECTIVES:

Upon completion of this project you will be able to:

Identify the major components of a refrigeration system.

Trace the refrigerant flow through the components of the refrigeration system.

Standard of performance:

The standard of performance of this project is 100 percent completion errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-I-3-P1	1/student
Pen or pencil	1/student

PROCEDURE

1. Use the schematic of the following refrigeration system to identify the components and the functions of each.

	COMPONENTS	FUNCTION
a.		
b.		
c.		
d.		
e.		

2. Using colored pencils provided by the instructor, color-code the refrigerant in the system as follows:

a.	Low-pressure liquid	- dark blue
b.	Low-pressure gas	- light blue
c.	High-pressure liquid	- dark red
d.	High-pressure gas	- light red

9B -75-655

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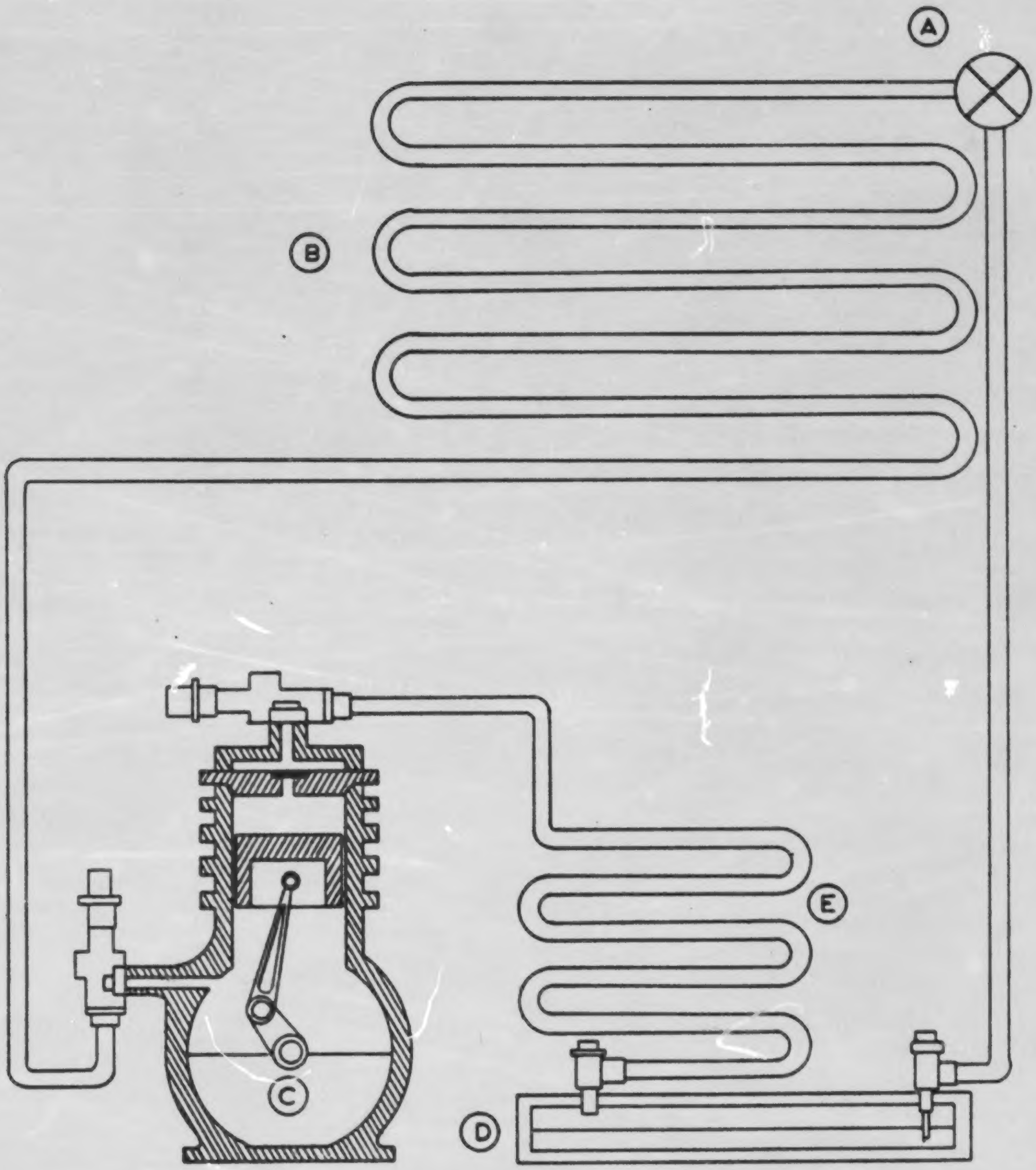

A
B
E
C
D

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-I-3-P2

CALCULATING HEAT LOADS AND EQUIPMENT SELECTION

OBJECTIVES

Upon completion of this project you will be able to:

Calculate the daily heat load of a walk-in cooler application.

Select the equipment required to handle the heat load.

Standard of performance:

The standard of performance of this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-1-3-P2	1/student
Pen or pencil	1/stud

PROCEDURE

Load Estimation Instructions: Use the load estimate form that follows to estimate the daily heat load of a problem given by the instructor.

(FOR ROOMS ABOVE 32°F)

DESIGN INFORMATION

Application:
Outside Ambient Temperature: ______ °F
Room Temperature: ______ °F
Temperature Difference(TD) ______ °F

Room Dimensions Outside
Length(L) ______ ft
Width(W) ______ ft
Height(H) ______ ft

Insulation
Type ____________
Thickness ______ in

Overall Wall Thickness:

Product Load:
____
____

Miscellaneous Loads
Number of People ____________
Electrical watts ____________
Other: ____________

SOLUTION

Outside Room Surface Area (A)
Front ________ Bottom ________
Back ________ L. End ________
Top ________ R. End ________
Total ________________

Room Dimension Inside
Length ________ ft
Width ________ ft
Height ________ ft
V = (Calculate on separate sheet)

I WALL LOAD
- (a) Area ____________ sq ft
- (b) Wall heat gain factor ____________ Btu/sq ft/24 hrs
- (c) Total load . . . . ____________ Btu/24 hrs

II AIR CHANGE LOAD
- (a) Volume ____________ cu ft
- (b) Air changes ____________ per 24 hrs
- (c) Heat removal ____________ Btu/cu ft
- (d) Total load . . . . ____________ Btu/24 hrs

III PRODUCT LOAD
1. Temperature reduction load
   - (a) Weight of product ____________ lbs
   - (b) Temperature reduction ____________ °F
   - (c) Specific heat ____________ Btu/lb°F
   - (d) Load . . . . ____________ Btu/24 hrs
2. Heat of respiration load
   - (a) Weight of product ____________ lbs
   - (b) Heat of respiration ____________ Btu/lb
   - (c) Load . . . . ____________ Btu/24 hrs

IV MISCELLANEOUS LOADS
- (a) People ________ X ________ X ________ = ____________ Btu/24 hrs
- (b) Watts ________ X ________ X ________ = ____________ Btu/24 hrs
- (c) Other ____________ Btu/24 hrs

V TOTAL REFRIGERATION LOAD ____________ Btu/24 hrs
VI SAFETY FACTOR (10% of total refrigeration load). ____________ Btu/24 hrs
VII TOTAL REFRIGERATION LOAD WITH SAFETY FACTOR ____________ Btu/24 hrs
VIII REQUIRED HOURLY CAPACITY = ____________ X 1/16 hrs ________ Btu/hrs

Equipment Selection

Problem: This walk-in box is utilized to store milk. The total heat load is 104,996 Btu per 24 hours. Refer to the tables provided in the study guide.

Fill the following blanks with the necessary information to select the evaporator and condensing unit.

Evaporator

Box temperature ____________

Temperature difference ____________

Btu rating ____________

Model number ____________

Condensing Unit

Evaporator suction temperature ________

Btu rating ________

Model number ________

Compressor motor horsepower ________

Refrigerant used ____________________

Problem: Eggs will be stored in this refrigerator. This total 24-hour heat load is 86,000 Btu. An air-cooled condensing unit should be used.

Evaporator

Box temperature ____________

Temperature difference ____________

Btu rating ____________

Model number ____________

Condensing Unit

Evaporator suction temperature ________

Btu rating ________

Model number ________

Compressor motor horsepower ________

Refrigerant used ____________________

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-I-3-P3

PLOTTING THE REFRIGERATION CYCLE WITH THE PRESSURE-ENTHALPY DIAGRAM

OBJECTIVES:

Upon completion of this project you will be able to:

Plot a representation of the refrigeration cycle on a pressure-enthalpy diagram.

Standard of performance

The standard of performance of this project is 100 percent completion, errorfree.

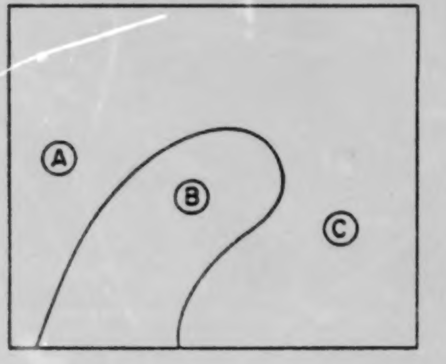
EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-1-3-P3	1/student
Pressure-Enthalpy charts	1/student
Pen or pencil	1/student

PROCEDURE

Instructions: Fill in the blanks below and plot a refrigeration cycle.

1. Identify the regions of the pressure-enthalpy chart below:

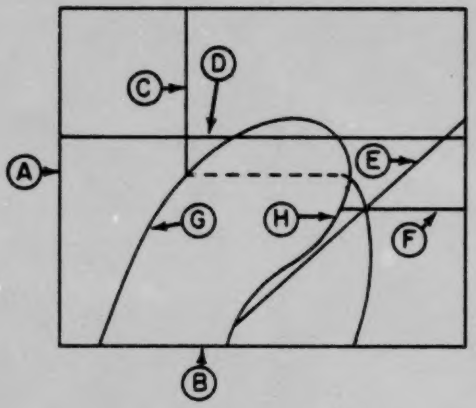


a. ______________________________

b. ______________________________

c. ______________________________

2. Identify the scales and lines on the pressure-enthalpy chart below:



a. ______________________

b. ______________________

c. ______________________

d. ______________________

e. ______________________

f. ______________________

g. ______________________

h. ______________________

3. Plot the refrigerating cycle of a system that is operating at the following conditions:

Low side gauge pressure - 37 psig

High side gauge pressure - 185 psig

REFRIGERANT 12

NO SUBCOOLING OR SUPERHEATING

PLOTTING THE REFRIGERATION CYCLE AND CHECKING OPERATION AND EFFICIENCY OF A SYSTEM USING THE PE DIAGRAM

OBJECTIVES

Upon completion of this project you will be able to:

Plot the refrigeration cycle on the chart and determine the operating efficiency of the cycle.

Standard of performance

The standard of performance of this project is 100 percent completion errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-1-3-P4	1/student
Pressure-Enthalpy chart	1/student
Pen or pencil	1/student

PROCEDURE

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Instructions: Plot the cycle of operation of each problem given below and fill in the blanks.

1. Problem No. 1. The system is operating with a condensing pressure of 275 psig and an evaporator pressure of 70 psig. This is a 20-ton system which uses R-22 as a refrigerant. Find the following:

a. Compression ratio____________________

b. Refrigeration effect____________________

c. Refrigeration loss____________________

d. Heat of compression____________________

e. Refrigerant circulated____________________

f. Compression work____________________

g. Coefficient of performance____________________

h. Compressor HP (theoretical)____________________

i. Total brake HP____________________

2. Problem No. 2. The system is operating with a condensing pressure of 350 psig and an evaporator pressure of 75 psig, with 10 degrees superheat and 20 degrees of subcooling. This is a 25-ton system which uses R-22 as a refrigerant. Find the following:

a. Compression ratio____________________

b. Refrigerant loss____________________

c. Refrigerant effect____________________

d. Heat of compression____________________

e. Refrigerant circulated____________________

f. Compression work____________________

g. Coefficient of performance____________________

h. Compressor HP (theoretical)____________________

i. Total brake HP____________________

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PREPARE THE MAN

SG 3AZR 54550-2-II-1

Department of Civil Engineering Training

Refrigeration and Air-Conditioning Specialist

MAJOR COMPONENTS, DOMESTIC AND COMMERCIAL REFRIGERATION SYSTEMS

May 1974

AIR TRAINING COMMAND

SHEPPARD AIR FORCE BASE

71-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

MAJOR COMPONENTS, DOMESTIC AND COMMERCIAL REFRIGERATION SYSTEMS

(Days 11-16)

UNIT	TITLE	PAGE
II-1	Major Components, Domestic and Commercial Refrigeration Systems	1

This supersedes SG 3AZR54550-2-II-1 and 2, 3 January 1973.

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

MAJOR COMPONENTS, DOMESTIC AND COMMERCIAL REFRIGERATION SYSTEMS

OBJECTIVE

This unit of instruction is designed to develop your understanding of the various components which may be found in refrigeration systems. You must know this information to service, operate, and adjust systems for proper operation.

INTRODUCTION

In previous units you have studied the fundamentals of refrigerating machines. No attempt was made to go into detail concerning the various mechanisms, but rather to show the fundamental principles to serve as the foundation and background of your specialty. Study this unit carefully and if necessary refer back to previous units. Poor knowledge, improper maintenance or service can definitely damage very expensive equipment.

COMPRESSORS

Types

There are basically three types of compressors in use today, reciprocating, rotary, and centrifugal. Centrifugal compressors are used widely in large applications and will be discussed in Block III.

Rotary compressors are usually limited to use in small fractional horsepower applications and are used in the domestic refrigeration field. They will be discussed later in this block of instruction.

The overwhelming majority of compressors used in refrigeration applications are the reciprocating type. This unit of instruction will cover only reciprocating compressors.

The purpose of the compressor in a system is twofold, first it removes the refrigerant vapor from the evaporator and reduces the pressure in the evaporator to a point where the desired evaporating temperature can be maintained. Second, the compressor raises the pressure of the refrigerant vapor to a level high enough so that the saturation temperature is higher than the temperature of the cooling medium available for condensing the refrigerant vapor.

Referring to figure 1, you will note the design of the reciprocating compressor is similar to a modern automobile engine, with a piston driven by a crankshaft making alternate suction and compression strokes in a cylinder equipped with suction and discharge valves. The reciprocating compressor is a positive displacement pump with many advantages which follow.

1. It is suitable for small displacement volumes.
2. It is quite efficient at high condensing pressures.
3. It is quite efficient at high compression ratios.
4. It is adaptable to a number of different refrigerants.
5. Liquid refrigerant may easily be run through connecting piping because of the high pressure created by the compressor.
6. It is durable, has simplicity of design and relative low cost.

Operation

Again referring to figure 1, a cross sectional view of the reciprocating compressor is shown. As the piston moves downward on the suction stroke, the pressure is reduced in the cylinder. When this pressure falls below the pressure in the suction line, the pressure differential causes the suction valves to open and forces the refrigerant vapor into the cylinder. As the piston reaches the bottom of its stroke and starts upward on the compression stroke, pressure is developed in the cylinder forcing the suction valve closed. The pressure in the cylinder continues to rise as the piston moves upward, compressing the vapor trapped in the cylinder. When this pressure exceeds the pressure existing in the compressor discharge line, the discharge valves are forced open, and the compressed gas flows into the discharge line and on to the condenser. When the piston starts downward, the pressure reduction allows the discharge valve to close because of the higher pressure in the condenser and discharge line, and the cycle is repeated.

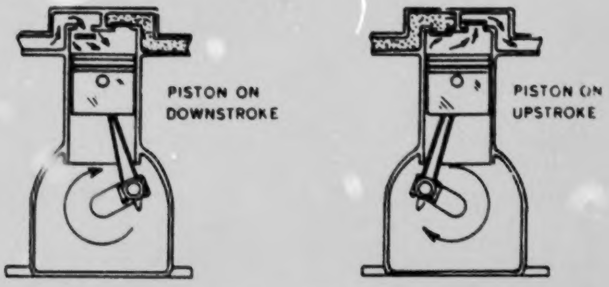

Figure 1.

For every revolution of the crankshaft, there is both a suction and compression stroke of each piston. For example; in a 1,750 rpm motor compressor, there are 1,750 complete suction and compression cycles in each cylinder each minute. For a 3,5000 rpm motor compressor, 3,500 complete cycles occur each minute.

Piston Displacement

The refrigerant boiling in the evaporator has a definite volume. The volume of the cylinder of the reciprocating compressor must be large enough to remove the refrigerant boiling off in the evaporator. If the volume is too small, vapor will remain in the evaporator and increase the evaporator pressure. As a direct result of the increased pressure in the evaporator, the boiling point of the refrigerant will rise. The piston of a cylinder, which has a volume of one cubic foot, would have to make 100 upward strokes a minute to compress 100 cu ft of vapor per minute. This volume swept by the piston during a certain time period is known as the piston displacement.

To determine the displacement of a single-acting compressor the following formula is used.

$$Q = \frac{D^2 \times L \times N \times RPM}{2200}$$

Q = Displacement in CFM
D = Cylinder bore in inches
L = Length of stroke in inches
N = Number of cylinders
RPM = Revolutions per minute

The theoretical capacity of a compressor can be figured by dividing its piston displacement by the volume of refrigerant to be circulated per ton of refrigerant. Earlier, using the pressure-enthalpy chart you figured the pounds of refrigerant circulated per ton. The volume of refrigerant circulated is found by dividing the pounds circulated by the density of the vapor being circulated. Density may be found in tables on the properties of refrigerant in commercial manuals or by using figure 2.

Volumetric Efficiency

In the preceding paragraphs it was assumed that the cylinder would fill completely with refrigerant vapor at the same pressure and temperature at which it left the evaporator. This does not hold true in the actual operation of reciprocating compressors. The volume and weight of the refrigerant that flows into a cylinder is always less than the theoretical capacity. This is so for several reasons, the first being the cylinder walls are warmer than the gas leaving the evaporator. This raises the temperature of the gas coming into the cylinder causing it to expand and prevent additional cold vapor from entering. A second reason is that the pressure in the cylinder is lower than the suction line and evaporator due to the downstroke of the piston. The vapor in the cylinder expands on entering the cylinder. Therefore, there is a smaller weight of refrigerant in each cubic foot of cylinder space. Another reason is the clearance space between the cylinder head and the top of the piston. In this clearance space a small amount of high-pressure vapor remains after the piston reaches the top of its stroke. This vapor reexpands on the downstroke of the piston taking up space in the cylinder. This decreases the weight of vapor that can flow into the cylinder.

The factors mentioned above determine the volumetric efficiency of a compressor. The volumetric efficiency may be defined as the ratio of the actual weight of refrigerant in a cylinder to the weight that the cylinder can theoretically hold.

Temp	Pressure		Density	
	PSIA	PSIG	Liq.	Vapor
-40	9.3	11.0*	94.67	0.26
-38	9.8	9.1*	94.45	0.27
-36	10.3	8.9*	94.28	0.28
-34	10.9	7.8*	94.08	0.30
-32	11.4	6.7*	93.87	0.31
-30	12.0	5.5*	93.70	0.33
-28	12.6	4.3*	93.50	0.34
-26	13.2	3.0*	93.30	0.36
-24	13.9	1.6*	93.10	0.38
-22	14.6	0.3*	92.90	0.39
-20	15.3	0.6	92.70	0.41
-18	16.0	1.3	92.50	0.43
-16	16.8	2.1	92.30	0.45
-14	17.5	2.8	92.10	0.47
-12	18.3	3.7	91.89	0.49
-10	19.2	4.5	91.69	0.51
- 8	20.1	5.4	91.49	0.53
- 6	21.0	6.3	91.28	0.55
- 4	21.9	7.2	91.07	0.57
- 2	22.9	8.2	90.87	0.60
0	23.8	9.2	90.66	0.62
2	24.9	10.2	90.45	0.65
4	25.9	11.2	90.24	0.67
6	27.0	12.3	90.03	0.70
8	28.2	13.5	89.82	0.73
10	29.3	14.6	89.61	0.76
12	30.5	15.8	89.39	0.78
14	31.8	17.1	89.18	0.81
16	33.1	18.4	88.96	0.85
18	34.4	19.7	88.75	0.88
20	35.7	21.0	88.53	0.91
22	37.1	22.4	88.31	0.94
24	38.6	23.9	88.09	0.98
26	40.1	25.4	87.87	1.01
28	41.6	26.9	87.65	1.05
30	43.1	28.5	87.43	1.09
32	44.8	30.1	87.20	1.13
34	46.4	31.7	86.98	1.17
36	48.1	33.4	86.75	1.21
38	49.9	35.2	86.52	1.25
40	51.7	37.0	86.30	1.29
42	53.5	38.8	86.07	1.34
44	55.4	40.7	85.94	1.38
46	57.4	42.7	85.60	1.43
48	59.3	44.7	85.37	1.48
50	61.4	46.7	85.14	1.53
52	63.5	49.8	84.90	1.58
54	65.7	51.0	84.66	1.63
56	67.9	53.2	84.43	1.68
58	70.1	55.4	84.19	1.74
60	72.4	57.7	83.94	1.79
62	74.8	60.1	83.70	1.85
64	77.2	62.5	83.46	1.91
66	79.7	65.0	83.21	1.97
68	82.3	67.6	82.97	2.03
70	84.9	70.2	82.72	2.09
72	87.6	72.9	82.47	2.16
74	90.3	75.6	82.22	2.22
76	93.1	78.4	81.96	2.29
78	96.0	81.3	81.71	2.36
80	98.9	84.2	81.45	2.43
82	101.9	87.2	81.19	2.50
84	104.9	90.2	80.93	2.58
86	108.8	93.3	80.67	2.66
88	111.2	96.5	80.41	2.73
90	114.5	99.8	80.14	2.81
92	117.8	103.1	79.87	2.90
94	121.2	106.5	79.61	2.98
96	124.7	110.0	79.33	3.07
98	128.2	113.5	79.06	3.16
100	131.9	117.2	78.79	3.25
102	135.6	120.9	78.51	3.34
104	139.3	124.6	78.23	3.44
106	143.2	128.5	77.95	3.53
108	147.1	132.4	77.66	3.63
110	151.1	136.4	77.38	3.74
112	155.2	140.5	77.09	3.84
114	159.4	144.7	76.80	3.95
116	163.6	148.9	76.50	4.06
118	167.9	153.2	76.21	4.17
120	172.4	157.7	75.91	4.29
122	176.9	162.2	75.60	4.41
124	181.4	166.7	75.30	4.53
126	186.1	171.4	74.99	4.65
128	190.9	176.2	74.68	4.78
130	195.7	181.0	74.37	4.91

* Inches of Mercury

Figure 2.

Compression Ratio

The volumetric efficiency of a compressor is not a constant quality. It depends on what is known as the compression ratio. This is the ratio between the head and suction pressure, or

$$\text{Compression Ratio} = \frac{\text{Head Pressure (psia)}}{\text{Suction pressure (psia)}}$$

As discussed in the preceding section the clearance space of a cylinder is left full of high-pressure gas at the end of the compression stroke. The higher the discharge pressure, the greater the density and pressure of this gas and the greater the volume it occupies on reexpansion. For this reason the capacity of the compressor decreases as the compression ratio increases.

Compressor Capacity Control

Loads on refrigeration and air-conditioning systems vary from full to a small percentage of full load. Some means must be used to control the capacity of the compressor to correspond to the load on the evaporator. If for example the load on an air-conditioning system falls low enough, the suction temperature may fall well below 32 °F before a balance point between the compressor and evaporator load is reached. In this case the final temperature of the air crossing the evaporator will be undesirably low, causing the moisture condensing on the evaporator to freeze. This will of course aggravate the condition by restricting airflow and forcing the suction temperature even lower. It is for this reason some method must be used to regulate the compressor capacity. In the following paragraphs some of these methods will be discussed.

ON-OFF CONTROL. One of the simplest forms of compressor capacity control is through the use of the low-pressure motor control found on most reciprocating compressors. This system is satisfactory where the loads are fairly constant and light loads are not encountered. On light loads the machine will tend to short cycle and impose severe stress on the electrical equipment. If started too frequently the motor may overheat and the contacts of the motor starter may be damaged. The starting current drawn from the line could cause voltage fluctuations that may affect other equipment on the same distribution system.

The operation of the on-off type control is as follows. The pressure tube of the low-pressure switch is connected to the compressor suction line and the electrical contacts are wired in series with the holding coil of the compressor motor starter. On a falling load the suction pressure drops below the desired limit, the switch opens and deenergizes the motor starter to stop the compressor. On a rising load the suction pressure rises to a predetermined point, the switch closes, energizing the motor starter and starts the compressor.

VARIABLE SPEED. The capacity of a compressor is in direct relationship to the speed at which it is turning. Therefore, controlling the speed of a compressor will control its capacity. One type employs a manual speed changing switch and a constant speed motor starter. This type of system is ideal where loads do not fluctuate widely. Another type employs two low-pressure controls and a two-speed motor starter. One pressure control places the unit in low speed on a decrease in load and the other cycles the unit.

HOT GAS BYPASS. This method employs a solenoid valve, see figure 3. This valve is closed for full capacity. The valve opens for half capacity and gas from one bank of cylinders goes back into the suction line. A check valve prevents the gas from the other bank of cylinders from backing into the suction line. This type of system should be avoided except where capacity reduction is infrequent and for short periods of time for the following reasons:

- There is no reduction in power consumption at reduced loads.
- The hot gas causes hot cylinder heads.
- There are noise and lubrication problems with this type of system.

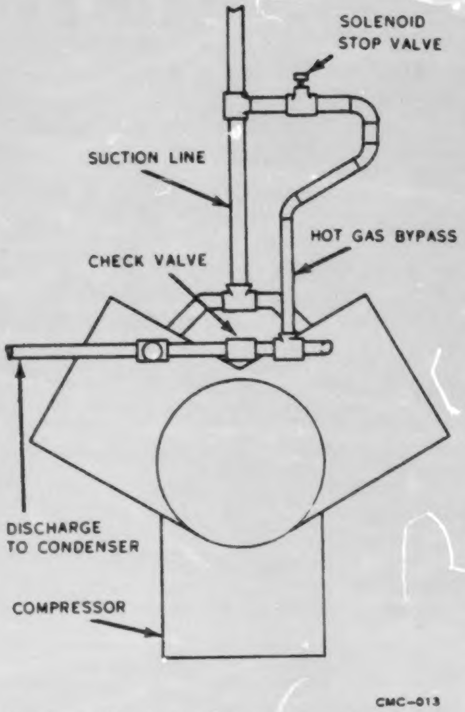

Figure 3. Hot Gas Bypass System

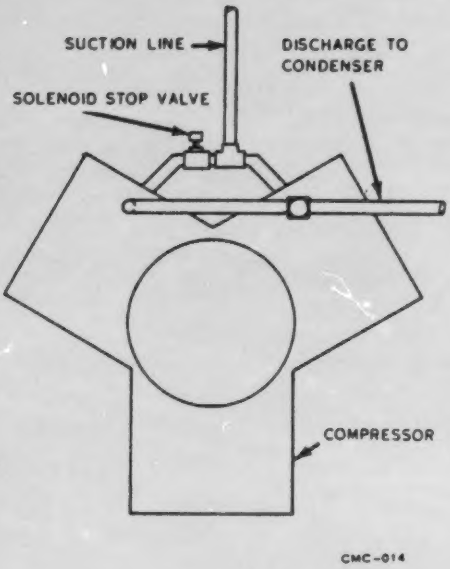

Figure 4. Cylinder Bypass System

CYLINDER BYPASS. In this system, the solenoid valve is installed so that it closes the suction line off to one bank of cylinders, see figure 4. The cylinders cannot pump but the valves continue to operate causing the following disadvantage: high vacuum is created in the suction manifold and the cylinder which causes oil pumping.

CYLINDER UNLOADERS. Capacity control is accomplished in this system by holding the suction valves open. Figure 5 shows a diagram of the hydraulic cylinder unloader. Suction pressure sensing variations in the load will load or unload each controlled cylinder. The major components of this system are the capacity control valve, hydraulic relay, unloader power element,and the unloader sleeve.

Operation. The operation can be traced in figure 5. The pressure from the crankcase is fed through a surge chamber which changes the pulsating pressure to a stabilized flow to the capacity control valve (1). As the increase of pressure enters the valve, an internal bellows is expanded and the pushrods attached to the needle and seat assembly pull the needle toward the seat. This action increases the control oil pressure. The increase of pressure in the crankcase is also passed through the oil pump to the hydraulic relay (2).

> NOTE: This pressure is true oil pressure plus suction pressure. The increased oil pressure will bleed through the port in the end of the relay piston and force the relay piston to move one notch for each increase of 2 psi. For each increase of 2 psi the repositioning opens a port leading to an unloader power element (3). There is one less cylinder unloader power element than total number of cylinders; this means that one cylinder will be fully loaded at all times.

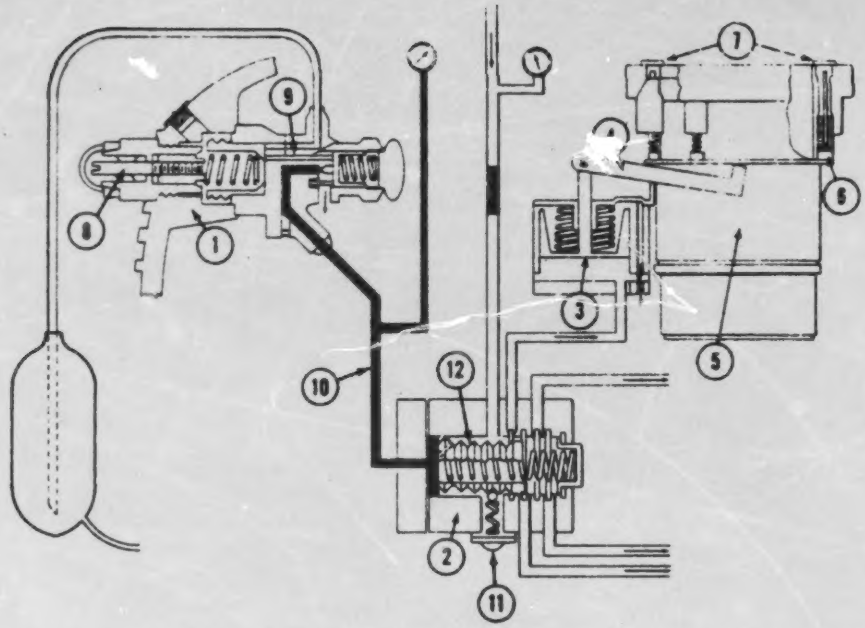

Figure 5. Cylinder Unloader Circuit

As the unloader element (3) has the increased power applied, it is forced against the piston face, opposing the spring pressure and pushing up on the lifting fork assembly (4). This action causes the lifting fork to drop, which allows the unloader sleeve (5) to drop. The dropping action of the unloader sleeve allows the pushpins (6) to fall against the face of the unloader sleeve allowing the suction disc (7) to seat on top of the cylinder and load the cylinder.

As the pressure decreases in the crankcase, the decrease through the capacity control valve (1) causes the bellows to contract and the pushpins (9) push the needle away from the seat decreasing the control oil pressure (10). This decreased control oil pressure will allow the spring pressure to reposition the piston, closing off feed-line ports to the unloader power elements one notch against the ball and seat assembly (11) for each 2 to 2.5 psi change in pressure. As the pressure is no longer being applied to the unloader power element (3) the internal spring pressure forces the excessive oil to return by gravity feed to the crankcase. The action of the lifting fork (4) forces up on the unloader sleeve (5). This lifting action pushes the lifting pin (6) against the disc type suction valve (7) raising it off the seat, unloading the cylinder.

Adjustment. The capacity control mechanism must be adjusted to maintain a balance between the load and compressor capacity. This adjustment is made by turning the external adjustment stem on the capacity control valve. Turning the adjusting stem clockwise (in) unloads the cylinder. Turning the adjusting stem counterclockwise (out) loads the cylinders.

The ideal setting of the capacity control valve is achieved when the first cylinder unloads at a pressure of 3 psi below the design suction pressure. The capacity control valve loads and unloads cylinders in steps to balance the compressor capacity with the heat load. The compressor must be fully loaded before the capacity control valve can be correctly adjusted. If it is impossible to fully load the system before setting the control valve, adjust the valve to give a minimum of cycling and make the final adjustment when the system is fully loaded.

Multiple Compressors

There are some installations where complete shutdown due to compressor failure would cause serious financial loss. In these instances the refrigeration load is broken up into two or more parts, each handled by a single compressor. This provides standby service and, under partial load, only the required number of compressors are operating. These systems will be covered in a later unit of instruction.

CONDENSERS

The condenser is basically a heat exchanger where the heat absorbed by the refrigerant during the evaporating process is given off to the condensing medium. The heat given off by the condenser is always greater than the heat absorbed during the evaporating process, because of the heat of compression. (This was covered in your study of the pressure-enthalpy diagram.) As the heat is given off by the high-pressure, high-temperature vapor, its temperature falls to the saturation point and the vapor condenses to a liquid, hence the name condenser.

Air-Cooled Condensers

This most commonly used condenser is of tube and external fin construction and dissipates heat to the ambient air. Heat transfer is efficiently accomplished by forcing large quantities of air through the condenser assembly. Air-cooled condensers are easy to install, easy to maintain, require no water and there is no danger of freezing in cold weather. However, an adequate supply of air is necessary and the fan may cause noise problems in large systems. In very hot regions the temperature of the ambient air may result in high condensing pressures, but if the condenser is properly sized they can be used in all climate regions.

Draw through fans which pull the air through the condenser, result in a more uniform flow through the condenser than the blow-through. Since even distribution of air will increase the condenser efficiency, the draw-through types are preferred.

Air-cooled refrigeration systems that are operated in low ambient temperatures are susceptible to damage due to low head pressure unless means of adequately maintaining normal head pressures are provided. The capacity of refrigerant control devices are dependent upon the pressure difference across the device. Control devices are selected for desired capacity with normal operating pressures. Abnormally low head pressure reduces the pressure difference across the expansion valve or refrigerant control resulting in insufficient refrigerant flow. This will cause erratic refrigerant feed to the evaporator, possible frosting of an air-conditioning coil and lower refrigerant velocity, permitting oil to settle out and trap in the evaporator causing a shortage of oil in the compressor.

CAPACITY CONTROL. To overcome the capacity and startup problems there are various solutions. The condenser may have multispeed fans, dampers over the condenser to control airflow, or the best solution to backflood the condenser with liquid refrigerant by using a head pressure control valve.

Water-Cooled Condensers

When an adequate supply of low cost condensing water is available, water-cooled condensers are often desirable because of the better condensing pressures, and better head pressure control is possible.

Because of water's excellent heat transfer ability, water-cooled condensers can be quite compact.

These condensers are of three basic types: (1) double tube, (2) shell and coil, and (3) shell and tube.

The double-tube condenser is one with a tube within a tube with the water flowing through the inner tube. This type is sometimes formed into a coil approximately 20" in diameter. It uses a counterflow of water and refrigerant for the greatest amount of heat transfer.

The shell-and-coil condenser is one with a copper coil enclosed in a steel shell. The water flows through the coil and the refrigerant is in the shell. The shell also acts as a receiver on a unit using this type of condenser. This type of condenser is very difficult to service, clean, and repair leaks on.

The shell-and-tube condenser is one with tubes inside a steel shell. This condenser permits a large amount of condensing surface in a small space and has the added advantage of being easy to clean and service. The water flows through the tubes and the refrigerant is in the shell. Like the shell-and-coil condenser, this also serves as a receiver.

Evaporative Condensers

This type of condenser is used where lower condensing temperatures are desired than are obtainable with air-cooled units, and the available water supply may not be adequate for heavy water usage.

This type of a condenser is essentially a condenser and cooling tower combined into a single unit. A diagram of an evaporative condenser is shown in figure 6.

Both air and water are used in the evaporative condenser. The water is pumped from the sump to a set of spray nozzles and sprays down over the condenser tubes back to the sump. The air is drawn from the outside at the bottom by a blower and is discharged back to the atmosphere on top of the condenser.

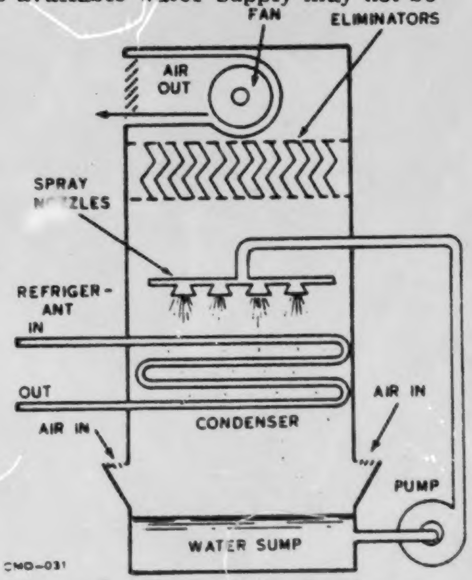

Figure 6. Evaporative Condenser

COOLING TOWERS

Although the cooling tower is not considered as an actual refrigerant condenser, its function in the system is so closely related to the operation and maintenance of water-cooled condensers, this heat rejection component of the system will be discussed at this time.

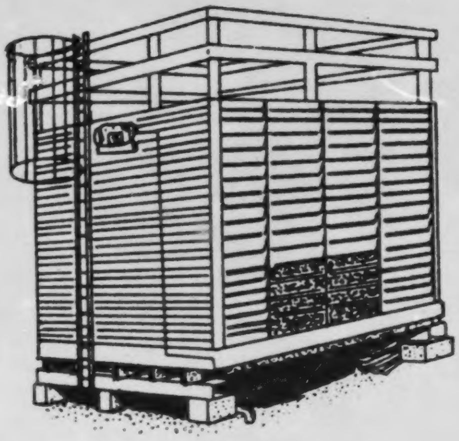

Figure 7. Cooling Tower

Cooling towers (see figure 7) are used to cool the water from the water-cooled condensers of refrigeration and air-conditioning systems. The hot water from the condenser is pumped to the top of the tower, then sprayed on a distribution deck where it passes through holes and falls onto the wetted deck. The cool water falls into the collection pan and the cycle begins again.

Air passing through the tower evaporates some of the water. The heat of evaporation comes from the water itself; therefore, when the water reaches the collecting tank at the bottom of the tower its temperature is 10 to 18° less than it was at the top of the tower. The smaller the droplets of water the more surface area is exposed to the action of the air and the faster the rate of evaporation. The same process takes place here that takes place when a swimmer comes out of the water. As long as the swimmer is under the water and not in contact with the air, he is relatively warm. However, when he steps out of the water into the air, evaporation takes place. The heat for this evaporation comes from the swimmer's body and leaves a feeling of being cold.

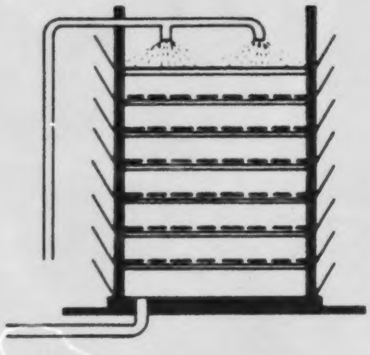

Figure 8. Schematic Diagram of a Natural Draft Cooling Tower

A basic cooling tower (figure 8) consists of water spray, a collecting pan, drain connections, and a structure of louvers or solid panels which form an enclosure or spray chamber. A pump is provided for the recirculation of the cooled condenser water. Most cooling towers are equipped with an adjustable bleed-off to help reduce scale and corrosion.

Types

There are two types of cooling towers; one is the atmospheric or natural draft tower which depends on wind velocity, the other is the forced draft type which uses a fan to force the air through the tower.

NATURAL DRAFT. A natural draft or atmospheric cooling tower is dependent on natural air movement through its structure for effective operation. This type of tower has louvered panels on all four sides to permit the wind to pass through the spray chamber. Structural members of these towers are usually made of steel, and the wetted deck of cypress or redwood. They are normally used for small refrigerating systems and are always located outdoors. To permit maximum circulation of air through them, they are placed on an elevated structure when adjacent to a building, or on the ground when they are placed a good distance from a building or other wind obstruction. All atmospheric towers must be placed away from wind obstructions to obtain the benefit of prevailing winds during the summer.

Natural draft towers are designed for a 3 to 5 mile wind velocity and are selected to cool the water to approximately 7° above the wet bulb temperature. The amount of water circulated through the tower spray system is at the rate of five gallons per minute per ton of refrigeration required.

FORCED DRAFT TOWERS. Forced draft towers are equipped with solid metal panels on all four sides which are mounted on structural steel members with openings for flow of inlet and discharge air. Fans are located either at the inlet or at the outlet of spray chamber depending on manufacturer's particular design. Normally, forced draft towers are used on large refrigerating systems and are installed either indoors or outdoors in any convenient space. Indoor installations are near the outside wall to reduce duct work to and from the outside. Sizes of the ducts are never smaller than the openings of the tower. Restrictions in ducts and louvers, and sharp or square bends are avoided since they reduce the airflow. Force draft towers are selected for the same wet bulb temperatures as natural draft towers and cool the water to approximately 7° above the wet bulb temperature. The amount of water circulated through the tower spray system is at the rate of three gallons per minute per ton of refrigeration required (see figure 9).

Regardless of whether a natural convection or a forced convection tower is used, 1.8 gallons of water must be evaporated per hour for each ton of refrigeration capacity.

Cooling Tower Components

The spray nozzles are used to distrubute and atomize the condenser water to the top of the tower. The distribution deck further distributes the water over the wetted deck. The wetted deck made of redwood or cypress slats slows the waterflow aiding in evaporative cooling of the water. Louvers are used to direct the airflow through the tower. The cool water falls into the collection pan or sump. An overflow pipe is installed in the sump to reduce water spillage and can be used for bleed-off control. The bleed-off line may also be installed on the waterline from the condenser to the spray nozzles. The float valve is installed in the water makeup line to start and stop the flow of makeup water. The water circulating pump supplies cool water from the cooling tower sump through the water-cooled condenser, to the spray nozzles (figure 9).

The forced draft tower has a fan to force air through the tower and eliminators to prevent water being pulled out by the fan.

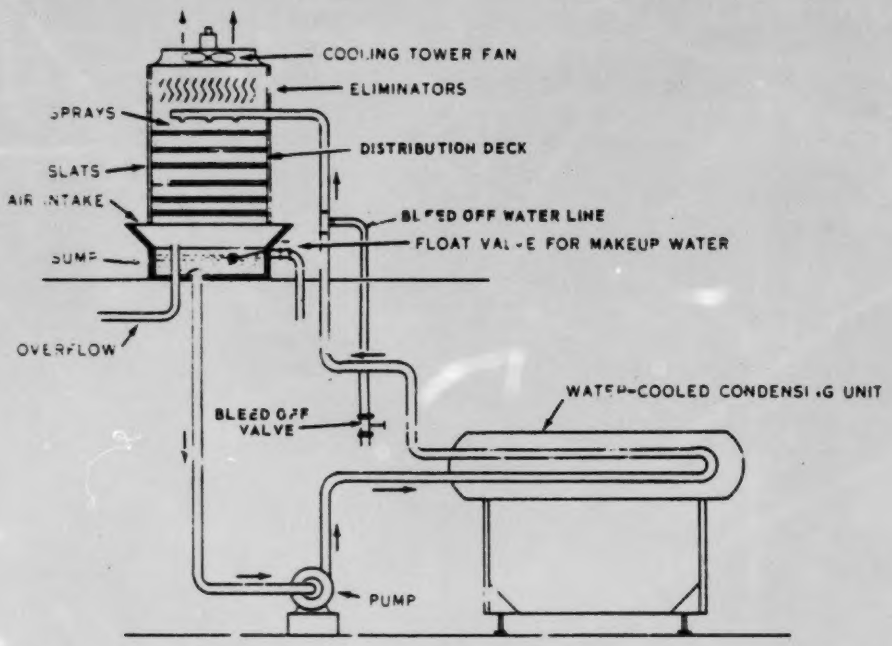
COOLING TOWER FAN
ELIMINATORS
SPRAYS
DISTRIBUTION DECK
SLATS
AIR INTAKE
BLEED OFF WATER LINE
FLOAT VALVE FOR MAKEUP WATER
SUMP
OVERFLOW
WATER-COOLED CONDENSING UNIT
BLEED OFF VALVE
PUMP

Figure 9. Schematic Diagram of a Mechanical Draft Cooling Tower

Cooling Tower Piping

Condenser water-circulating piping is usually of galvanized steel pipe and cast-iron fittings. Sufficient numbers of valves, flanges, and unions are installed so that the pump and condenser may be disconnected easily. Gate valves are used in the lines since they offer less resistance to the waterflow. Globe-type drain and vent valves are installed at all low and high points to drain or vent the piping system. Multicondenser systems have valves on inlet and outlet water connections to each condenser so that condensers may be disconnected without interfering with the operation of the rest of the condenser water circulating system. Pipe connections to the cooling tower, condenser, and pumps should never be smaller than the inlet or outlet connections of the equipment. The pump inlet connection to the cooling tower pan is always the same pipe size as the fitting on the pan for a distance of five feet if the connection is vertical, and for the entire length if it is horizontal. The pump inlet connection at the tower pan is protected by a wire screen to prevent debris from entering the piping system.

Capacity Control

The amount of heat removed from the condenser may be controlled by one of the following methods. When these methods are used together, there is a more efficient control. Figure 10 shows the three main capacity control systems.

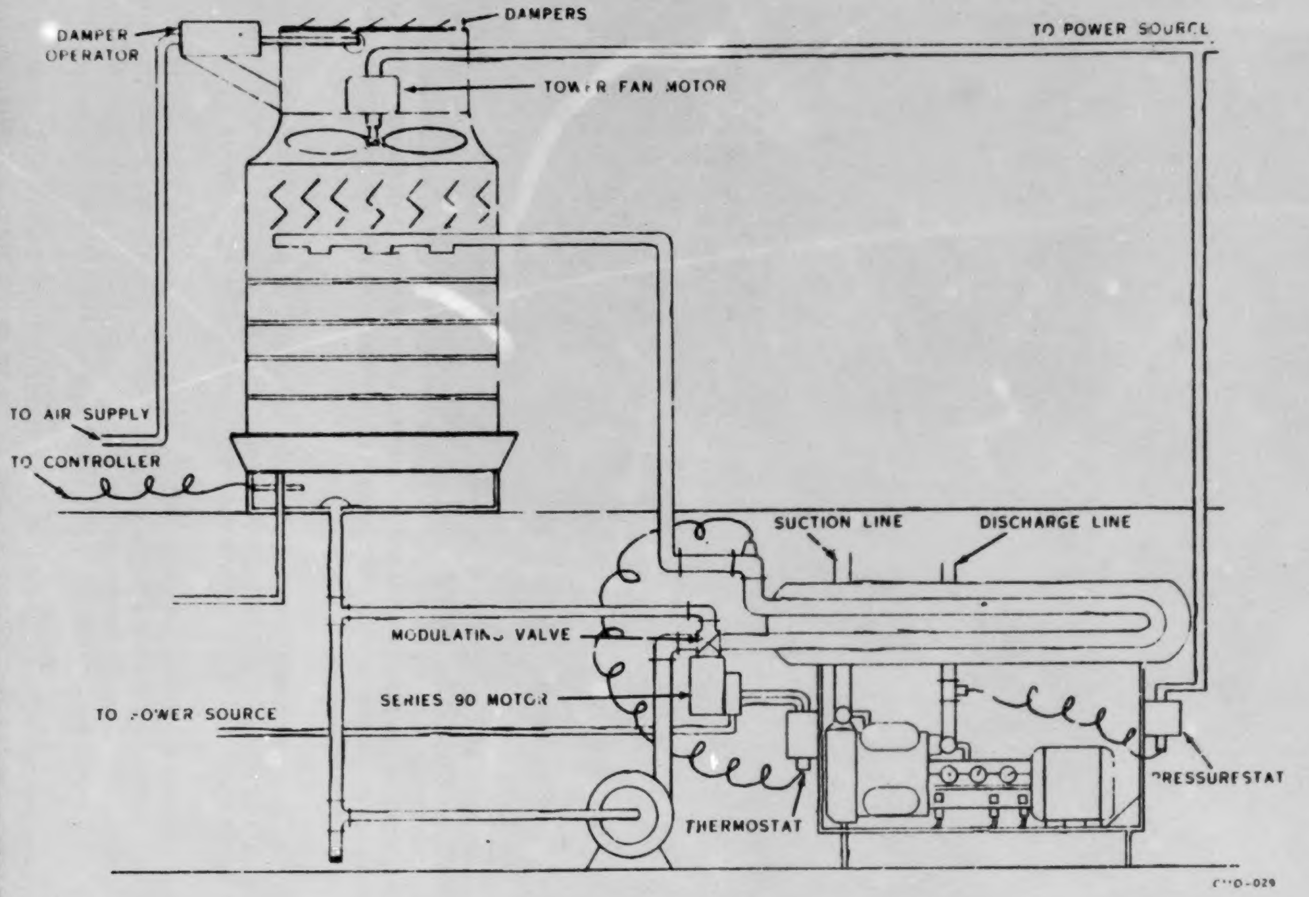
DAMPER OPERATOR
DAMPERS
TO POWER SOURCE
TOWER FAN MOTOR
TO AIR SUPPLY
TO CONTROLLER
SUCTION LINE
DISCHARGE LINE
MODULATING VALVE
SERIES 90 MOTOR
TO POWER SOURCE
PRESSURESTAT
THERMOSTAT

Figure 10. Cooling Tower Capacity Control Diagram

MODULATING VALVE. This valve is operated by a Series 90 electric motor and a thermostat. The thermostat senses the temperature of the water leaving the condenser. It has an insertion type sensing element that is installed in the outlet waterline from the condenser. The thermostat is set for a desired temperature. When the water temperature decreases, the valve closes the waterline from the tower to the condenser. This increases the condensing temperature and raises the head pressure. When the condenser water temperature rises to the cut-in setting on the thermostat the bypass portion of the valve closes. This allows the water to flow from the condenser to the tower.

PRESSURESTAT. In this method of capacity control the cooling tower fan is cycled by a pressurestat that is connected to the compressor discharge line. When the discharge pressure increases, the pressurestat will cycle the fan to the ON position. This removes the heat from the water, reducing the pressure. When the discharge pressure decreases to the pressurestat setting, the fan is cycled off.

MODULATING DAMPERS. These dampers are located in the tower fan discharge airflow. The operation of the dampers is controlled by a pneumatic thermostat. A pneumatic damper operator positions the dampers according to what is called for by the thermostat. A remote bulb sensing element is installed in the collecting pan of the cooling tower. When the condensing pressure increases the tower water temperature increases. This is sensed by the thermostat. The thermostat sends a signal to the controller to open the dampers. This allows more air to go through the water to remove the heat. When the temperature is reduced the thermostat signals the damper operator to close the dampers.

WATER TREATMENT

Water treatment is a very important part of the operation of cooling towers and consequently water-cooled condensers. Without treatment of the water, the formation of scale, corrosion, or algae will have a direct result on the efficiency of the system. The refrigeration specialist need not be a chemistry major to perform water treatment. He should though, know how to recognize water problems and the treatment and prevention of these problems.

Corrosion is the destruction of metal by chemical or electrochemical action. Rust is a form of corrosion. All metals containing iron will rust if exposed to the effects of air and moisture. Water increases the corrosion or rusting process.

Scale is the residue or deposits left by water. This can be demonstrated by placing some water containing minerals in a pan and boiling away the water. The minerals will be left in the pan. If this process is continued several times, the pan will become covered with a coat of these minerals. These minerals are called scale.

Algae is small microscopic plant and animal life that forms and grows in water. Algae if uncontrolled can become a big problem in water towers, tanks, piping, pumps, and condensers.

Acids, Bases and Salts

Acids, bases, and salts are chemical compounds associated with waters used in refrigeration systems. The early chemists discovered that compounds had distinct tastes. Vinegar and lemon juice had a sour taste so the chemists named then "acids" from the Latin word "Acidus," meaning sour.

The second group of compounds such as caustic soda and lime had a bitter taste. This group of compounds would destroy the sourness of acids and would act as a foundation for the manufacturing or making of the third group. Since they acted as a foundation they were called bases.

The third group of compounds was obtained by mixing a base and an acid together. These compounds had a salty taste and were called salts. When these salts are mixed with water, we call them brines. Table salt mixed with water produces a sodium chloride brine. Cold brines are used in ice plants to circulate around fresh water ice cans to produce ice. Brines are very corrosive to metals; therefore, corrosion inhibitors are employed to reduce corrosion.

Testing for pH

Just as a thermometer measures the intensity of heat, pH measures the intensity of an acid or base in solution. pH means potential hydrogen; a hydrogen atom that has lost its electron (H+); a positive hydrogen atom; a positive hydrogen ion. Where many hydrogen atoms lose their electrons, the water solution containing these hydrogen ions becomes very aggressive; so aggressive, in fact, that the water will eat metal right off iron pipes. This aggressive water is acid in nature.

pH determines the degree of acid or base in solution. With litmus paper and "P" indicator we can determine whether a solution is acid or base, but we cannot determine the degree of intensity. With pH comparators, we can determine not only the nature of the solution but also the intensity of acid or base. Acids contain more hydrogen ions (H+) than hydroxyl ions (OH-) and range in pH from 6.9 to zero. Bases contain more OH- ions than H+ ions and range in pH from 7.1 to 14.

Pure water is made up of H_2O molecules but also contains H+ ions and OH- ions in equal amounts. The pH of pure water is 7.0 which is neutral; neither acid nor base. When there are impurities in water, usually this balance is disturbed and there is more H+ or OH-. This causes the water to be acid or base. Going a step further, acids can be identified as those substances which, when dissolved in water, increase the hydrogen ion (H+) concentration; bases as those substances which, when dissolved in water, increase the hydroxyl (OH-) ion concentration. HCL is an acid. NaOH is a base.

It has been found that the hydrogen and hydroxyl ion concentration of pure water is 0.0000001 gram per liter or $0.0000001=1/10^6$ grams. The pH value of the water would then be expressed as 6.0. A pH of 5.0 is 10 more times more acid than a pH of 6.0.

The relation between H+, OH-, and pH values is shown in figure 11.

TEST FOR ACIDS. A very simple test is to place litmus paper in the acid solution. Acid turns blue litmus paper red. Another test for acids is to check the solution with phenolphthalein "P" indicator. "P" indicator remains colorless when placed in acids.

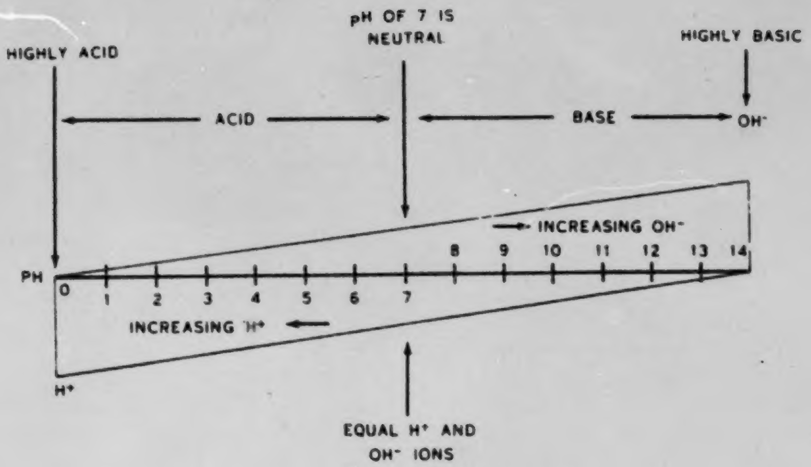
pH OF 7 IS NEUTRAL
HIGHLY ACID
HIGHLY BASIC
ACID
BASE
OH⁻
INCREASING OH⁻
PH
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
INCREASING H⁺
H⁺
EQUAL H⁺ AND OH⁻ IONS

Figure 11.

TESTS FOR BASES. Bases are probably not as well known as acids but they are just as important.

Sodium hydroxide is a white, crystalline solid. It is soluble in water, bitter to the taste, feels slippery between the fingers and burns the skin. It is more commonly known as lye or caustic soda. Next to sulfuric acid, sodium hydroxide is probably the most widely used chemical. It is a very strong base and must be handled with caution.

Bases turn red litmus paper blue. When the pH is above 7.9, bases turn "P" indicator red. Bases are used to neutralize acids.

pH Adjustment. Scale may be slowed down or stopped by reducing the pH value of the water. This may be done by adding inhibited sulphuric acid to the water. An inhibited acid will not dissolve metal. As seen in figure 12, scale occurs at a pH of 9.0 and above. Acids reduce pH value. If we reduced the pH at 8.0, scale would usually be controlled. Acids should be fed into large systems with an automatic proportional feeder to prevent excessive acid additions. The pH should never be adjusted below 7.0.

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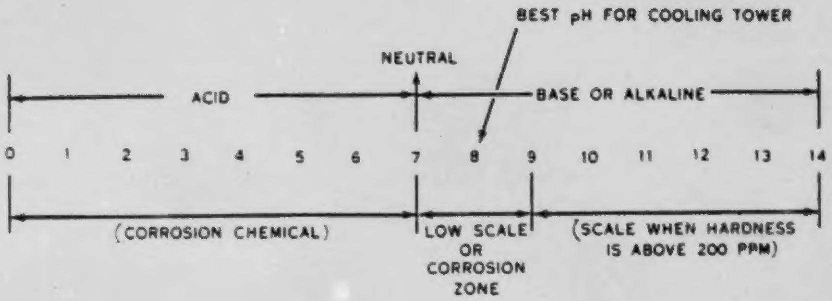

BEST pH FOR COOLING TOWER
NEUTRAL
ACID
BASE OR ALKALINE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
(CORROSION CHEMICAL)
LOW SCALE OR CORROSION ZONE
(SCALE WHEN HARDNESS IS ABOVE 200 PPM)

Figure 12. pH Adjustment

Corrosion

As was mentioned earlier, corrosion is the destruction of metal by chemical or electrochemical action.

CHEMICAL CORROSION. Corrosion caused by chemical reaction occurs when the pH of the water solution is below 7.0. During chemical attack, the metal dissolves into the acid solution. Metal is eaten away uniformly. If corrosion is not arrested, failure of the pipe or tubing will take place. The pH requirement for minimum corrosion or scale formation in chilled and cooling water systems is between 7.0 and 9.0.

ELECTROCHEMICAL REACTION. Electrochemical action is similar to the reaction which takes place in the battery of your car. When two dissimilar metals are in contact, such as brass and steel, a cell results. Metal will be removed from one and will either go into solution or be deposited upon the other. Nonuniform corrosion is produced by electrochemical cells.

AC electrical equipment should not be grounded to waterpipes that show signs of electrochemical corrosion, as this makes more active cells with a resultant increase in the corrosion rate.

General Methods of Preventing Corrosion. Various methods may be employed to prevent corrosion. Oxygen and carbon dioxide may be removed from the water by chemical or mechanical means. Chemicals are added to the water to form protective films on the metal and direct current is impressed on the metal to prevent cell-type corrosion.

Corrosion Prevention by Chemical Treatment. The most common chemical used to control corrosion are chromates and polyphosphates.

Scale

Scale is a white deposit consisting of compounds of calcium and magnesium. Scale on the inside of water-cooled condensers presents a serious problem because it reduces the efficiency of the condensing unit.

SCALE FORMATION. The evaporation of water from a cooling tower leaves certain solids behind. Recirculation of the water and the accompanying evaporation causes the concentration of solids to increase. If this concentration is not controlled, scale will result.

METHODS OF REMOVING SCALE. It is much easier to prevent scale than it is to remove it, but there will be times when scale removal is necessary. Two general methods are used to remove scale; the mechanical and the chemical method.

Mechanical Method. Scale is removed mechanically by brushing, scraping, and grit blasting. Mechanical methods are very effective on hard, rough surfaces such as evaporative coolers, cooling tower louvers, spray chambers, water pumps, etc. On soft copper and brass surfaces, however, the mechanical method may cause scratches, cuts, and nicks which make a good starting point for scale. In such cases, chemical methods should be employed.

Chemical Method. Chemical methods of removing scale from equipment consist of dissolving scale deposits in a cleaning solution consisting of dilute hydrochloric acid. Whenever possible, commercial inhibitor powder should be added to the scale cleaning solution. The inhibitor will limit metal corrosion without materially reducing the solvent action on the scale deposit.

METHODS OF PREVENTING SCALE. There are many methods of preventing scale and every job presents an individual problem. The following methods in the order listed are usually the most effective in preventing scale.

- Turbidity control
- Once-through water system
- Bleed-off adjustment
- Surface active agents
- pH adjustment
- Zeolite softening

Once-Through Water. Where an abundant supply of cheap water is available, cooling water may pass through the equipment once and undergo a slight rise in temperature (10 to 15°). Little difficulty from scale will be experienced with this method unless the hardness is more than 200 ppm.

Surface Active Agents. Surface active agents, such as micromets, are polyphosphates which have the property of keeping calcium and magnesium compounds (scale forming) in solution longer than normal.

There are a number of phosphate water treating materials on the market, some of which are readily soluble and some slowly soluble, but in any case, it is necessary for the metaphosphate to be in the system all of the time. Phosphates that are in solution form, or readily soluble should not be dumped into the cooling tower since they will immediately start leaving with the bleed and within a few hours the residual will be down below the required amount.

Either a feeding device or a slowly dissolving phosphate with controlled solubility must be used. Results will not be obtained unless the phosphate is fed into the water at a fairly constant rate.

One manufacturer supplies inexpensive plastic mesh feeding bags into which are placed a slowly soluble phosphate material in plate form. (See figure 13.) This plate material gives a very uniform solution rate because the solubility rate depends upon

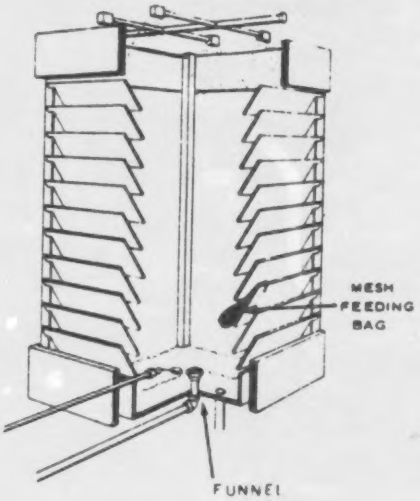


Figure 13. Location of Mesh Feeding Bag

the surface area and the surface area remains fairly constant as the plates become thinner. Thus, the rate of feed is very constant for several months, or until about 60 percent of the material has dissolved. The desirable features of using the feeding bags are that the bags are inexpensive, easy to install and when placed above sump water level they do not overtreat the system when the equipment is not in use because the chemical dries out and stops feeding.

Other materials in granular form are available but they must be used in a feeder in the makeup water line. If slowly soluble phosphate is used, place it in a suitable container so that it will not be thrown away each time the tower is drained.

Turbidity. It is measured in parts per million (ppm). One ppm turbidity means one pound of clay or mud in a million pounds of water. The particles of clay are suspended in the water. This means that they can settle out or be filtered. Solids in solution such as salt dissolved in water cannot be filtered.

Bleed-Off Adjustment. In a system using a cooling tower of evaporative condenser, bleed-off is the best method of preventing scale formation. Bleed-off limits the concentration of hardness in solution in the circulating water. If the bleed-off plugs up, the concentration of scale-forming solids will increase rapidly and scaling will result.

Bleed-off should be set at a minimum of one gallon per hour per ton of cooling. If scale forms, the bleed-off should be gradually increased. The maximum bleed-off allowed is four gallons per hour per ton of cooling. A greater rate would result in a waste of water. If scale does continue to form when bleed-off is set at maximum, then it is necessary to chemically treat the circulating water or soften the makeup water.

Location of Bleed Line. The bleed line should be located as illustrated in figure 14.

One or both points A and B must be higher than the water level in the pan to prevent the water from syphoning out when the system is not running.

Use gate valve C only where pressure in the bleed line makes shutoff desirable for removing pipe cap B. Always locate valve C within easy reach of pipe cap. Valve C must be left wide open and not used for regulating flow.

Bleed line discharges through drilled hole in removable pipe cap. Select drill size to give proper bleed rate. Leave cap fingertight so it is easy to remove for cleaning.

Leave an eight-inch clearance between pipe cap and drain, so quart bottle can be used to measure bleed rate.

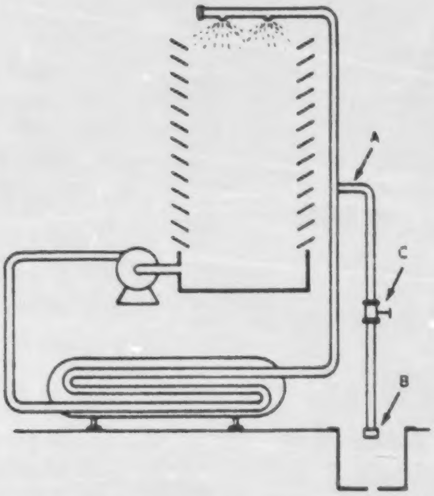


Figure 14. Location of Bleed Line

Bleed rate can be measured by determining the number of seconds it takes to fill a quart bottle. Bleed rate in gallons per hour equals 900 divided by the number of seconds required to fill the bottle.

Remember, no method of water treatment will work satisfactorily unless the bleed-off rate is maintained correctly.

Algae

Algae are slimy living growths of one cell animals and plants. They may be brought in by birds or high winds. Algae thrives in cooling towers and evaporative condensers where there is abundant sunlight and high temperatures to carry on their life process. Algae formations will plug nozzles and prevent proper distribution of water which will in turn cause high condensing pressures and lowered efficiency.

Chlorine base algaecides are used to control or prevent the growth of algae, Calcium Hypochlorite being commonly used on Air Force installations. 1.5 ppm of this chemical will control the growth of algae satisfactorily.

EVAPORATORS

The evaporator is that part of the low pressure side of the refrigeration system in which the liquid refrigerant boils or evaporates, absorbing heat as it changes to a vapor. It accomplishes the actual purpose of the system - "Refrigeration."

Classification

Evaporators used in air-conditioning systems are generally classified as direct expansion coils or the shell-and-tube chiller.

DIRECT EXPANSION COIL. This evaporator is widely used for cooling air. It consists of a series of tubes with fins attached for a greater heat transfer surface. The direct expansion coil may be either of the dry or flooded type. In the flooded type a float is used to keep a constant level of refrigerant in the evaporator. The dry type uses an expansion valve metering device.

SHELL-AND-TUBE. This evaporator is used to provide chilled water for air-conditioning systems. This type also may be of the flooded or dry type. The water is in the tubes in the flooded type and one-half to three-quarters of the tube bundle is submerged in liquid refrigerant. This type evaporator is used on larger units. In the dry type the refrigerant is in the tubes and the water circulates over the tube bundle. This type evaporator is used on smaller units.

REFRIGERANT METERING DEVICES

There are six different types of refrigerant metering devices: (1) hand expansion valve, (2) automatic expansion valve, (3) thermostatic expansion valve, (4) capillary tube, (5) low side float, and the (6) high side float. In this section we will discuss the automatic and thermostatic expansion valves.

Automatic Expansion Valve

The automatic expansion valve maintains a constant pressure in the evaporator by opening and closing in response to changes in the load on the evaporator. Figure 15 shows a diagram of the automatic expansion valve. The valve consists of a needle and seat, a pressure bellows or diaphragm, and an adjustable spring.

OPERATION. The operation of the valve is automatic. Once the tension on the spring is adjusted for a desired pressure, the valve will automatically adjust the flow of refrigerant so that the desired evaporator pressure is maintained no matter what the load on the evaporator is. This is accomplished as a result of evaporator pressure working against spring pressure. Evaporator pressure rises. If the pressure rises above 15 psig it will override the spring pressure closing the valve off.

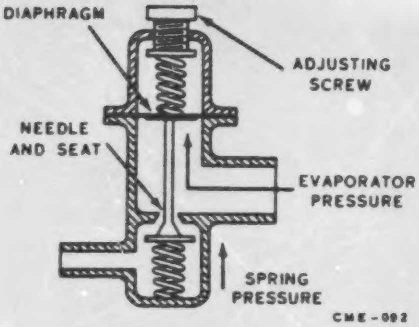

DIAPHRAGM
ADJUSTING SCREW
NEEDLE AND SEAT
EVAPORATOR PRESSURE
SPRING PRESSURE
CME-092

Figure 15. Automatic Expansion Valve

The operating characteristics of the valve are such that the valve will close off when the unit cycles off and remain closed. Some refrigerant remains in the evaporator and continues boiling after the compressor cycles off. This increases the pressure in the evaporator over the spring pressure causing the valve to close.

Thermostatic Expansion Valve

The thermostatic expansion valve is the most widely used metering device because of its high efficiency and adaptability to any type application. It maintains a constant degree of superheat in the evaporator allowing the evaporator to be completely filled with refrigerant no matter what the load on the system is. Because of this, it is very suitable for systems with wide load variations.

The principal parts of the valve are: the needle and seat, a diaphragm or bellows, a remote bulb connected to one side of the diaphragm or bellows, and an adjustable spring, see figure 16.

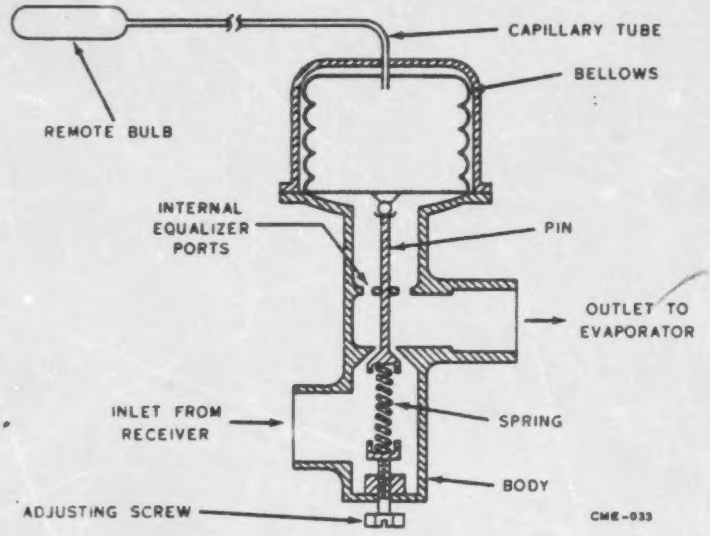

CAPILLARY TUBE
BELLOWS
REMOTE BULB
INTERNAL EQUALIZER PORTS
PIN
OUTLET TO EVAPORATOR
INLET FROM RECEIVER
SPRING
BODY
ADJUSTING SCREW
CME-033

Figure 16. Thermostatic Expansion Valve Construction

OPERATION. The operation of the thermostatic expansion valve results from the interaction of three independent forces, (1) evaporator pressure, (2) spring pressure, and (3) remote bulb pressure. Remote bulb pressure tends to open the valve and the combination of evaporator and spring pressure tend to close the valve.

An example of the operation is as follows: referring to figure 17 let's assume that R-12 refrigerant is boiling in the evaporator at a temperature of 24°F. Evaporator pressure (P_1) is 23.9 psig corresponding to a temperature of 24°. Assume further that the spring tension is adjusted to exert a pressure (P_2) of 6.2 psi, so the pressure tending to close the valve is 30.1 psig, the sum of P_1(23.9) and P_2 (6.2). If there isn't any pressure drop in the evaporator we can safely say that the temperature and pressure of the refrigerant are the same throughout the evaporator as long as there is a liquid and vapor mixture. However, at some point (B) near the end of the evaporator all the refrigerant will have changed to a vapor. From this point (B) on, the vapor will continue to pick up heat, becoming a superheated gas. This increases the temperature while the pressure of the gas remains constant. In this case let's assume the vapor is superheated from 24° to 32° (8° superheat) from point B to the remote bulb location at point C. The temperature of the refrigerant in the remote bulb will be the same as the vapor in the line (32°). This pressure is exerted on the diaphragm of the valve tending to open the valve. In the example above the pressure tending to close the valve ($P_1 + P_2 = P_3$) so the valve will remain in whatever position it is in. The valve will remain in this position until there is a change in superheat unbalancing the valve one way or the other.

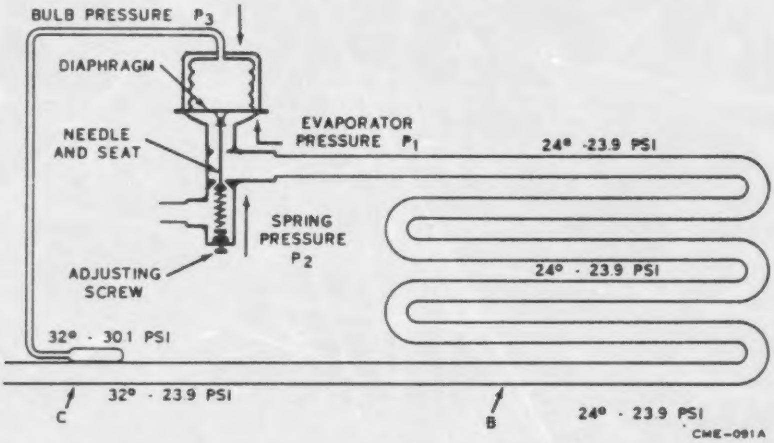


Figure 17. Thermostatic Expansion Valve Operation

Thermostatic Expansion Valve with External Equalizer

The refrigerant drops in pressure as it goes through the evaporator, so the boiling point of the refrigerant will also drop with the pressure. As long as the pressure drop is small it has little effect, but if it is large the temperature at the outlet of the evaporator will be considerably lower than at the inlet. This has an adverse effect on the valve in that a higher degree of superheat is required to balance the valve. In this case an externally equalized valve must be used to compensate for the pressure drop.

This can be shown by using the same example as shown in figure 17 but allowing for an 8 psi pressure drop in the evaporator (figure 18). The following would occur: The boiling point of the refrigerant at the inlet of the evaporator is 24° with a pressure of 23.9 psig (P_1) pushing against the diaphragm. The spring tension is adjusted at 6.2 psi (P_2) so a remote bulb pressure ($P_1 + P_2 = P_3$) of 30.1 psi (P_3) is required to balance the valve. In the previous example 8° superheat was required to balance the valve, but let's assume that the refrigerant has a pressure drop of 8 psi. This will drop the pressure at the outlet of the evaporator to 15.9 psig resulting in a drop of boiling point to 12°F. This means that the suction gas will have to be superheated from 12° to 32° (20°F) to provide the proper pressure in the remote bulb to balance the valve. To obtain this much superheat, point B must be backed up in the evaporator making a larger portion of the evaporator ineffective. This, in turn, reduces the capacity and efficiency of the unit.

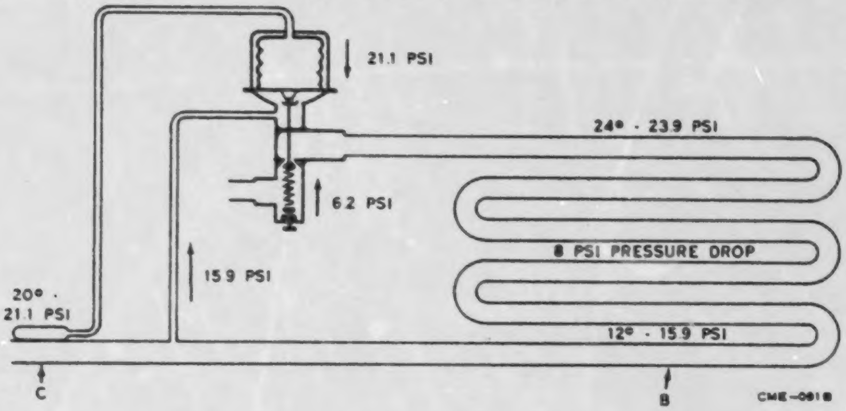


Figure 18. Large Pressure Drop Effect

OPERATION. To compensate for this pressure drop an externally equalized valve may be used. Referring to figure 18 notice that a small line from the evaporator outlet allows evaporator outlet pressure (P_1) to work against the diaphragm instead of inlet pressure. In this way the pressure drop has no effect on the degree of superheat required because P_1 is now 15.9 psi instead of 23.9 psi. Therefore, to balance the valve a remote bulb pressure of 22.1 psi ($15.9 + 6.2 = 22.1$) or 20° is required maintaining an 8° superheat setting.

ACCESSORIES

A number of accessory items are used in refrigeration systems for specific purposes, and their requirement in a particular system depends on the application.

Heat Exchangers

A heat exchanger (figure 19), whether used in refrigeration, heating, or any other application is a device for transferring heat. In the refrigeration industry, a heat exchanger is used to transfer heat from the hot liquid line into the cool suction line. A typical heat exchanger installation is illustrated in figure 20. The suction vapor (at a low temperature) goes through the inside tube in one direction and the hot liquid goes through the outside tube in the other direction. The hot liquid in the outside tubes keeps the heat exchanger from sweating. For best efficiency, the heat exchanger should be installed in the refrigerated space.

The counterflow effect of the hot liquid on cool vapor increases the heat transfer rate.

Advantages of Heat Exchangers

There are several advantages of using heat exchangers.

1. Minimizes flash gas.

2. Sweating or frosting of the suction line is minimized or eliminated

3. Flooding of liquid refrigerant to the compressor is minimized or eliminated.

4. Liquid enters the expansion valve at a lower temperature.

This advantage is very important in low temperature application. The hot liquid that comes from the receiver must have its temperature reduced in the evaporator before it can be evaporated. This means that heat is being carried into the evaporator by the hot liquid. In passing through the expansion valve, part of the liquid vaporizes and takes up the sensible heat from the rest of the liquid, reducing its temperature to that of the evaporator.

As an example, if one pound of 100° F liquid passed through the expansion valve into an evaporator with a temperature of 0°, about 1/16 of the pound would be vaporized reducing the 100° F liquid to 0°. Therefore, there would be only 15/16 of a pound of liquid left to produce refrigerating effect.

5. Increase compressor efficiency.

At air-conditioning temperatures, a heat exchanger will increase the volume of the suction gas enough to offset any advantage gained by reducing the amount of flash gas in the evaporator. This has caused several manufacturers of air conditioning equipment to eliminate the use of heat exchangers in their systems. However, when you consider the following conditions, it becomes obvious that heat exchangers can be an advantage to all systems.

All compressors must have an oil film on the sides of the cylinder to reduce friction between the cylinder and piston. If this film of oil is full of refrigerant each time the piston goes down, the refrigerant in the oil will evaporate in the cylinder. This reduces the amount of vapor the cylinder can remove from the evaporator. A heat exchanger will increase the temperatures of the suction gas. This, in turn, increases the temperature of the cylinder wall and the oil, which results in a thinner film of oil on the cylinder wall. The thin oil film can hold very little refrigerant so the piston can remove more vapor from the cylinder each stroke.

A heat exchanger may be manufactured by soldering the liquid line to the suction line. This is not very effective but it will help to reduce suction line sweating.

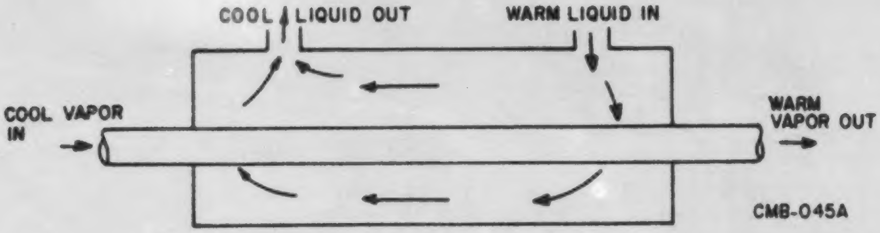

COOL LIQUID OUT
WARM LIQUID IN
COOL VAPOR IN
WARM VAPOR OUT
CMB-045A

Figure 19. Heat Exchanger (Shell and Tube)

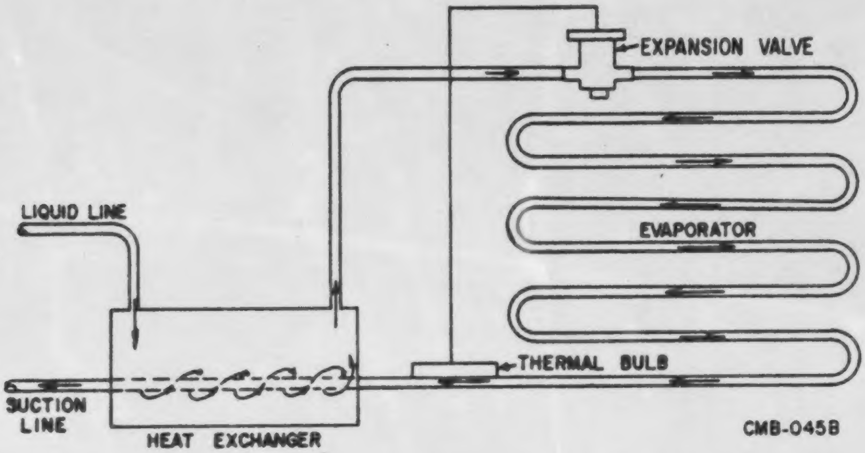

EXPANSION VALVE
LIQUID LINE
EVAPORATOR
THERMAL BULB
SUCTION LINE
HEAT EXCHANGER
CMB-045B

Figure 20. Typical Heat Exchanger Installation

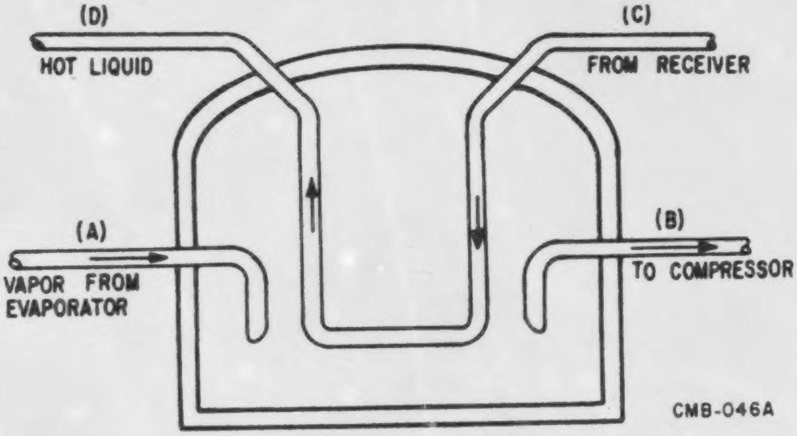

(D)
HOT LIQUID
(C)
FROM RECEIVER
(A)
VAPOR FROM EVAPORATOR
(B)
TO COMPRESSOR
CMB-046A

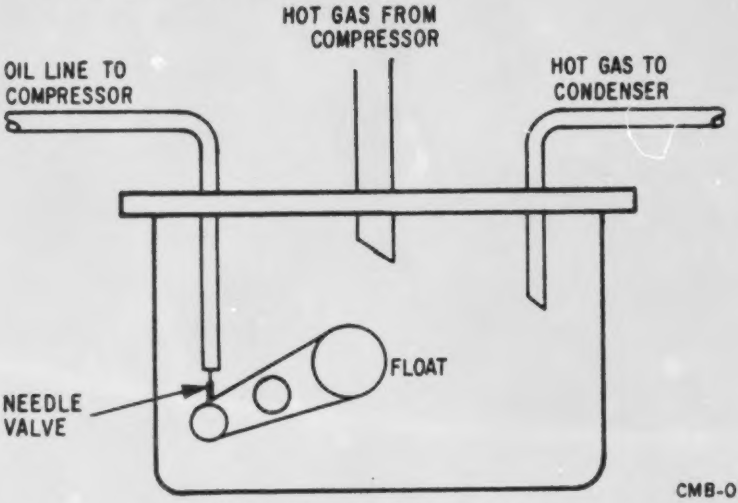
Figure 21. Accumulator

Accumulators

An accumulator is in reality a heat exchanger, but it does more than a heat exchanger does. The accumulator (figure 21) is a tank installed in the suction line as near the evaporator as possible. The vapor and any "flood over" liquid will enter the accumulator at point A. The liquid will fall to the bottom of the tank but the vapor can escape through line B to the compressor. Hot liquid from the receiver flows through line C and loses its heat to the liquid in the bottom of the tank. This exchange of heat forces the liquid to vaporize and is removed by the compressor through line B. After the exchange of heat, the cooled liquid continues to the expansion valve through line D. The accumulator is used on systems operating at 0° F and below.

Oil Separators

Oil separators (figure 22) are just what the name implies. They separate the oil from the vapor. An oil separator consists of an enclosed steel cylinder with a float and needle valve inside, a gas line from the compressor, a gas line to the condenser, and an oil return line to the compressor crankcase. As the hot vapor and oil come from the compressor, the oil falls to the bottom of the oil separator and the vapor goes to the condenser. When enough oil has accumulated, the float rises, opening the needle valve (the needle valve is always below the level of the oil). The high side pressure forces the oil to return to the low side of the compressor.


HOT GAS FROM COMPRESSOR
OIL LINE TO COMPRESSOR
HOT GAS TO CONDENSER
FLOAT
NEEDLE VALVE

CMB-046B

Figure 22. Oil Separator

Most expansion systems operating at temperatures above 0° F do not need an oil separator. Water coolers, low-temperature systems, and complex multiple installations operate much more efficiently if an oil separator is installed. The oil separator is insulated to prevent the discharge vapor from condensing to a liquid.

An oil separator is not a vital part of a refrigeration system and is not a cure-all for all cases of oil logging. Figure 23 shows a typical installation.

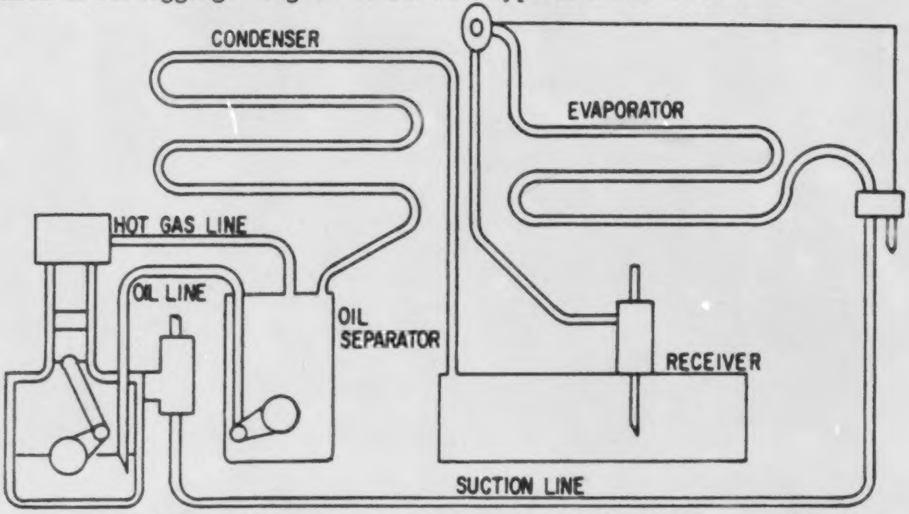

CONDENSER
EVAPORATOR
HOT GAS LINE
OIL LINE
OIL SEPARATOR
RECEIVER
SUCTION LINE

Figure 23. Typical Oil Separator Installation CMB-045C

MOISTURE

Moisture in refrigerating machines constitutes a very important problem for both the manufacturer and serviceman. Engineering has solved most of the mechanical problems in refrigeration while producers have virtually eliminated difficulties due to refrigerants unless those are mishandled. For the most part, satisfactory lubricating oils have been provided, reducing trouble from this source to a minimum. However, moisture is still found in some machines. Absence of moisture is absolutely essential for satisfactory machine operation. It is, therefore, imperative that moisture be eliminated during the manufacturing process, and the entrance of moisture in a system be guarded against in all fields of operation. If moisture does get into the system, the removal must be accomplished as soon as possible.

Cause of Moisture

Moisture may get into a system as the result of:

1. Faulty drying methods at the factory.
2. During assembly or service operation in the field.
3. Low side leaks (this can only happen if the low side is below atmospheric pressure or operating in a vacuum).
4. The breaking down of some hydrocarbon in the oil that produces moisture (caused by excessive operating temperature).
5. Moisture in the oil (this happens very often if the container holding the oil is left open for any period of time).
6. Moisture in the refrigerant (manufacturing methods will sometimes allow moisture to get into the refrigerant).

Effect of Moisture

Moisture in a refrigeration system may result in one or more of the following effects:

1. "Freezing up" at the expansion device (this can only happen if the temperature is below 32° F).
2. Corrosion of metal to form sludge (this condition will stop up or clog the expansion device and screen).
3. Copper plating (this condition will result in the piston sticking in the cylinder).

Ice separates from the freon, chloride, and butane refrigerants whenever the amount of moisture is great enough and the temperature of the refrigerant low enough. This accounts for the formation of ice in the expansion valve, capillary tube, and evaporator.

In low temperature units, a restricted expansion valve or capillary tube may result from the separation of wax from the oil (this condition can be eliminated by using a dewaxed oil).

The corrosion of metals occurs anytime water and refrigerants come in contact. With some metals, this corrosion is very slow, but with others, it becomes much faster. The following information will give you an idea of how and why this corrosion occurs.

1. Water and sulfur dioxide combine to form sulfurous acid (H_2SO_3). This is a mild form of the acid that is used in automobile storage batteries. All of us are familiar with the corrosion effect of battery acids.
2. Water and methyl chloride combine to form hydrochloric acid (HCl). This acid is used to clean the rust from iron before soldering.
3. Water and Freon combine to form hydrofluoric acid (H_2F_2). This acid is used to etch glass. The combining of water and Freon is very slow and only a small amount of the acid is formed. Some servicemen in the field claim that water in a Freon system will not cause corrosion, but if the water is left in the system long enough, it will give trouble.

Driers

If, despite all precautions, some moisture finds its way into the system, it must be reduced to an absolute minimum for satisfactory operation. This can be done by the use of a desiccant (drying agent).

A drier (figure 24) consists of a shell with a screen and filter at each end and the intervening space filled with a drying agent. The drier contains a chemical which has the property of removing moisture either by chemical or mechanical action. A drier is usually installed in the liquid line and should be placed in a vertical position with the line from the receiver connected to the bottom.

INLET
OUTLET
CMH-020

Figure 24. Drier

CALCIUM CHLORIDE. This is a chemical desiccant that may be used with all refrigerants. It will not reduce the moisture content to a very low level, but is satisfactory for ordinary refrigeration systems. When calcium chloride absorbs excessive amounts of moisture, a highly corrosive liquid is formed which will escape and cause disastrous results. A drier containing this chemical should not be left in the system over 24 hours.

CALCIUM OXIDE. This is a cheap and efficient desiccant. Its principal disadvantage is that it powders upon the absorption of excessive amounts of moisture, and the powder being very fine may pass through the filter.

CALCIUM SULPHATE. This is in a granular form, and it has some dust but not as much as calcuim oxide and with the correct filter does not cause any difficulty.

ALUMINUM OXIDE. This desiccant removes acid and moisture by adsorption. It may be used with any refrigerant.

SILICA GEL. This is the most popular drying agent. It is slower than some of the others but it may be left in the system indefinitely.

Driers are rated according to the horsepower of the compressor motor. If no data is available, use one pound of desiccant for each 10 pounds of refrigerant in the system.

SYSTEM PROTECTIVE DEVICES

Vibration Eliminators

On large installations where hard copper tubing is used, vibration eliminators must be used. Vibration eliminators are made of corrugated copper tubing with a braided bronze protecting cover. They are installed in both the discharge and suction lines and absorb the vibration of the compressor. High-pressure flexible hose is also used as a vibration eliminator, particularly in automobile air conditioning.

Fusible Plugs

These plugs consist of a bushing with the inside space filled with a soft alloy. This soft alloy is the weakest point in the system. If the high side pressure should go too high, the soft alloy will blow out. The fusible plug is easily replaced and it eliminates damage to some high-priced unit in the system.

Pressure Relief Valves

These valves have the same purpose as the fusible plugs. When the pressure reaches a predetermined point, this valve will open and relieve the excessive pressure. As soon as the pressure has been reduced, the valve will close.

There are two types of these valves in common usage--the adjustable and the nonadjustable. The adjustable type can be set to open at any pressure desired. The pressure should be set approximately 20 percent above the maximum operating pressure. For a Freon-12 system using an air-cooled condenser, this would be 230 to 235 psi. The nonadjustable is set at the factory. The pressure setting is normally stamped on the top of the valve. When using a valve of this type, make sure the setting is high enough so that the valve will not open during operation but is low enough to protect the equipment.

Strainers

Regardless of how careful the serviceman performs his job, he will allow some small bits of metal, dirt, or other foreign matter to enter the refrigeration system.

Strainers are used to catch and hold these small foreign particles before they damage the compressor or clog up the expansion valve. Strainers are made from fine mesh wire and are designed to hold a great deal of foreign material before they become stopped up. Strainers may be located in either the liquid line or the suction line, or both. There should always be a strainer at the inlet of a refrigerant control and in the compressor just before the vapor enters the cylinder.

TYPES OF STRAINERS. There are several types of strainers.

1. Line Strainer. This strainer is installed in the liquid line. The strainer area is normally 20 times larger than the line. It is cleaned by removing the unit and blowing dry air or refrigerant through it backward.

2. "Y" Strainer. This strainer consists of a "Y"-shaped frame containing a removable screen. The frame is installed in the line and the screen is removable without removing the strainer frame from the line.

3. Angle Strainer. This strainer is always installed where the line makes a 90° angle. It is possible to remove and clean the screen without disturbing the lines.

4. Finger Strainer. This strainer is a fine mesh screen in a cylindrical form. It is installed at the inlet of expansion valves and in the compressor valve plate.

Mufflers

Where quiet operation is essential, specially designed mufflers may be installed to reduce compressor noise. These mufflers are installed in the discharge line near the compressor.

Summary

You have seen how the various components of a refrigeration and air-conditioning system function, and their relationship to each other in making up the entire system. Through careful study of this unit you should have an insight into the problems that may arise and the procedures required to maintain troublefree systems. Proper operation of the compressor, condenser, evaporator, metering devices, cooling towers, and all system accessories should be your goal as a competent, proficient specialist.

References:

1. Textbook; Modern Refrigeration and Air Conditioning, Althouse, Turnquist, Bracciano
2. Textbook; Trane Refrigeration Manual

REFRIGERANT PIPING

Refrigerant flowing through refrigerant lines has a drop in pressure due to friction between the refrigerant and the walls of the tubing. We cannot avoid this pressure drop but can minimize its effect by installing the proper line size. The longer a line, the more valves and fittings in the line, the greater this pressure drop will be. This must be compensated for by using larger lines to avoid pressure losses which reduce the capacity and efficiency of the system.

Suction Lines

The suction line is the most critical line in the system. It must have a high enough velocity to return the oil to the compressor. Minimum velocities are: 500 fpm on horizontal runs and 1000 fpm on vertical runs with a maximum velocity of 4000 fpm to avoid excessive noise.

The suction line must also have a minimum pressure drop to prevent reduction of compressor capacity. This pressure drop should not exceed 2 psi on R-12 or 3 psi on R-22 for air-conditioning applications.

SIZING SUCTION LINES. Charts such as the one shown in figure 25 are used to figure suction line size. This chart is based on a 40° suction and a 105° condensing temperature. If the unit has other than these conditions the design tonnage must be corrected. Figure 26 has correction factors to be used before going to the line sizing chart. To correct the tonnage, multiply it by the correction factor and use this new figure as your tonnage.

You will notice in figure 25 that some figures are omitted on the left side of the chart. Here, the velocity is below the recommended minimum. The tonnage figures omitted on the right side of the chart are for velocities above the recommended maximum.

Figure 27 is a chart for the equivalent length to add to the line for valves and fittings installed in the line.

The velocity of the gas must also be checked after sizing the line, see figure 28. This chart is also based on design conditions of 40° suction and 105° condensing temperatures. Use the correction chart, figure 29, to correct the tonnage if other than these conditions exist. The tonnage is multiplied by the correction factor to obtain corrected tonnage.

Length in Feet	Pressure Drop	O. D. Copper Tubing									
		1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8	3 1/8
30	0.3				1.1	2.1	3.7	6.0	12.2	22.0	34.4
	0.6		0.6	1.0	1.5	3.1	5.3	8.6	17.5	31.7	49.6
	1.0	0.4	0.8	1.3	2.0	4.1	7.1	11.3	23.1	41.5	
	2.0	0.6	1.2	1.9	3.0	6.0	10.1				
40	0.3						3.2	5.1	10.5	19.0	29.7
	0.6			0.9	1.3	2.6	4.6	7.4	15.2	27.4	42.7
	1.0	0.4	0.7	1.1	1.7	3.5	6.1	9.7	19.8	35.6	56.0
	2.0	0.5	1.0	1.6	2.5	5.1	8.7	14.1			
50	0.3							4.5	9.4	16.8	26.0
	0.6				1.2	2.3	4.1	6.6	13.5	24.2	37.6
	1.0		0.6	1.0	1.5	3.1	5.3	8.6	17.5	31.7	49.6
	2.0	0.5	0.9	1.4	2.2	4.5	7.7	12.5	25.3		
75	0.3								7.5	13.6	21.0
	0.6					1.9	3.3	5.3	10.9	19.6	30.5
	1.0			0.8	1.2	2.5	4.3	6.9	14.2	25.3	39.8
	2.0	0.4	0.7	1.2	1.8	3.6	6.2	10.0	20.2	36.8	57.5
100	0.3									11.5	18.0
	0.6						2.8	4.5	9.4	16.8	26.0
	1.0				1.1	2.1	3.7	6.0	12.2	22.0	34.4
	2.0		0.6	1.0	1.5	3.1	5.3	8.6	17.5	31.7	49.6
125	0.3										15.8
	0.6							4.0	8.2	14.9	23.1
	1.0					1.9	3.3	5.3	10.9	19.6	30.5
	2.0		0.5	0.9	1.4	2.8	4.7	7.7	15.6	28.0	44.0
150	0.3										
	0.6								7.5	13.6	21.0
	1.0						3.0	4.8	9.9	17.8	30.0
	2.0			0.8	1.2	2.5	4.3	6.9	14.2	25.3	39.8
175	0.3										
	0.6								6.8	12.4	19.3
	1.0						2.8	4.4	9.1	16.3	25.3
	2.0				1.2	2.3	4.0	6.4	13.1	23.6	37.1
200	0.3										
	0.6									11.5	18.0
	1.0							4.1	8.5	15.2	23.7
	2.0				1.1	2.1	3.7	6.0	12.2	22.0	34.4
	0.3										
	0.6										15.8
	1.0								7.5	13.6	21.0
	2.0					1.9	3.3	5.3	10.9	19.6	30.5

Figure 25. Suction Line Sizing Chart

Cond. Temp.	Suction Temperature										
	0	5	10	15	20	25	30	35	40	45	50
85	1.46	1.36	1.29	1.21	1.13	1.07	1.02	0.97	0.91	0.87	0.82
90	1.50	1.39	1.32	1.23	1.16	1.10	1.04	0.99	0.93	0.89	0.84
95	1.53	1.43	1.35	1.26	1.19	1.12	1.07	1.01	0.95	0.91	0.86
100	1.57	1.47	1.38	1.30	1.22	1.15	1.10	1.04	0.98	0.93	0.88
105	1.62	1.50	1.42	1.33	1.25	1.18	1.12	1.06	1.00	0.95	0.90
110	1.66	1.55	1.46	1.37	1.28	1.21	1.15	1.09	1.03	0.98	0.92
115	1.71	1.59	1.50	1.40	1.32	1.24	1.18	1.12	1.05	1.00	0.95
120	1.76	1.64	1.54	1.44	1.36	1.28	1.21	1.15	1.08	1.03	0.97
125	1.82	1.69	1.59	1.49	1.40	1.31	1.25	1.18	1.11	1.06	1.00
130	1.88	1.74	1.64	1.54	1.44	1.36	1.29	1.22	1.15	1.09	1.03

Figure 26. Correction Factors for R-12 Suction Lines

Line Size	Globe Valves-Sol. Valves	Angle Valves	Ell, Short Radius	Ell, Long Radius	Line Flow Tee	Branch Flow Tee
1/2	70	24	4.5	3.1	1.5	6.5
5/8	72	25	5.5	3.8	2.2	8.3
3/4	75	25	6.5	4.5	3.0	9.7
7/8	78	28	7.9	5.4	3.8	12.2
1 1/8	87	29	2.8	2.0	2.5	8.0
1 3/8	102	33	3.4	2.4	2.9	10.3
1 5/8	115	34	3.9	2.8	3.2	12
2 1/8	141	38	5.3	3.4	3.9	16
2 5/8	160	44	6.5	4.4	4.6	20
3 1/8	185	53	8.0	5.1	5.4	25
3 5/8	216	65	10.0	6.4	6.7	29.8

Figure 27. Equivalent Lengths for Valves and Fittings

An example of sizing a suction line is as follows:

A system using R-12 with a capacity of 25 tons has a suction temperature of 25° and a condensing temperature of 115°. Find the suction line size if the line is 25-feet long and contains 3 short radius ells, and one solenoid valve.

SOLUTION:

Referring to figure 26 the correction factor is 1.24.

Corrected tonnage is 1.24 X 25 = 31 tons.

Referring to figure 25 estimate the size line to be used so that the equivalent length for the valves and fittings may be figured. This figure at 30 feet is 2 5/8-inch line which will handle 41.5 tons.

Now go to figure 27 and figure the equivalent length of the valves and fittings.

3 short radius ells	-	19.5 ft.
1 solenoid valve	-	160.0 ft.
actual length of line	-	25.0 ft.
		204.5 ft.

Refer back to figure 25 and check the line size to be used for the equivalent length of 204.5 feet. From figure 25 we find that a 200 feet a 3 1/8-inch line will carry 34.4 tons and at 250 feet it will carry 30.5 tons. We can be safe in saying it will handle a 31-ton load.

To check for the proper velocity in the suction line do the following:

Referring to figure 29 find the correction factor for velocity, 1.41.

Corrected tonnage is 1.41 X 25 = 35.25 tons.

Refer to figure 28 and we find that the velocity for a 35-ton load using a 3 1/8-inch suction line is approximately 2300 fpm, which is sufficient for oil return.

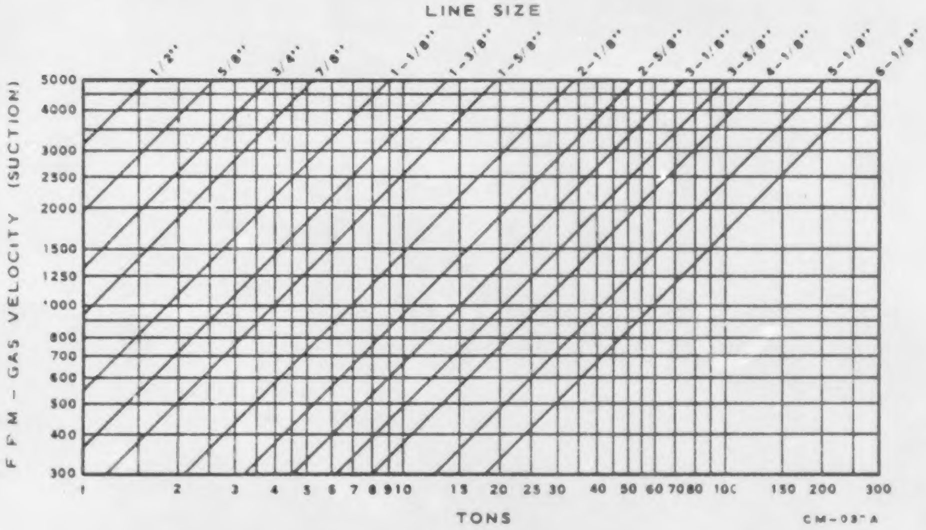


Figure 28. Line Velocities

Cond. Temp.	Suction Temperature										
	0	5	10	15	20	25	30	35	40	45	50
85	2.06	1.84	1.71	1.49	1.35	1.22	1.10	1.00	0.91	0.83	0.76
90	2.11	1.89	1.75	1.53	1.38	1.25	1.13	1.03	0.93	0.85	0.78
95	2.16	1.93	1.80	1.56	1.41	1.27	1.15	1.05	0.95	0.87	0.79
100	2.21	1.98	1.84	1.60	1.45	1.31	1.18	1.07	0.98	0.89	0.81
105	2.28	2.04	1.89	1.64	1.48	1.34	1.21	1.10	1.00	0.91	0.83
110	2.34	2.09	1.94	1.69	1.52	1.37	1.25	1.13	1.03	0.93	0.85
115	2.40	2.15	2.00	1.74	1.56	1.41	1.28	1.16	1.05	0.96	0.88
120	2.48	2.22	2.06	1.79	1.61	1.45	1.31	1.19	1.08	0.99	0.90
125	2.55	2.28	2.12	1.85	1.66	1.50	1.35	1.23	1.11	1.02	0.92
130	2.64	2.36	2.19	1.90	1.71	1.54	1.39	1.26	1.15	1.04	0.95

Figure 29. Suction Line Correction Factor

Discharge Lines

The discharge line must be given almost the same consideration as the suction line.. The pressure drop isn't as critical but velocity must be sufficient to insure oil flow with the refrigerant vapor. The same velocity pressures as for suction lines apply to discharge lines: 500 fpm on horizontal runs, and 1000 fpm on vertical runs, and a maximum velocity of 4000 fpm.

Pressure drop for discharge lines are a maximum of 4 psi for R-12 systems and 6 psi for R-22 systems.

SIZING DISCHARGE LINES. Charts such as the one shown in figure 30 are used for sizing discharge lines. This chart is also based on 40^{o} suction and 105^{o} condensing temperatures. If the unit has other than these temperatures, the tonnage must be corrected using figure 31.

These charts are set up the same way as the charts on suction lines with the figures omitted on the left and right of the chart being too low or too high velocity.

Figure 27 is also used on the discharge line for figuring equivalent lengths for valves and fittings.

Velocity of the gas in discharge lines are checked by using figure 32 with the tonnage correction factor to be used for velocity in figure 33 when conditions are other than 40^{o} suction and 105^{o} condensing temperatures.

An example of sizing a discharge line is as follows:

Using the same system as with the suction line find the size of the discharge line if the line is 27 feet and contains 2 short radius ells and one compressor shutoff valve (angle).

SOLUTION:

Referring to figure 31 the correction factor is 1.00 so the corrected tonnage will remain at 25 tons (1.00 X 25 = 25 tons).

Next, refer to figure 30 to find the estimated line size. Using the 30 feet figure we find that a 1 5/8-inch line will give a 30-ton capacity.

Now go to figure 27 and figure the equivalent length of the fittings and valves:

2 short radius ells	-	7.8 ft
1 angle valve	-	34.0 ft
Actual length of line	-	27.0 ft

Length in Feet	Pressure Drop	O.D. Copper Tubing									
		1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8	3 1/8
20	1	0.8	1.5	2.5	3.8	7.7	12.7	21.1	43.2	77.5	121
	2	1.2	2.2	3.6	5.6	11.1	18.7	30.0			
	3	1.4	2.7	4.5	6.9	13.8	23.1				
	4	1.7	3.1	5.2	8.0	16.0					
30	1		1.2	2.0	3.1	6.2	10.5	17.0	34.8	62.5	98
	2	0.9	1.7	2.9	4.5	9.0	15.2	24.6	50.5	90.5	
	3	1.2	2.3	3.6	5.6	11.1	18.7	30.0			
	4	1.4	2.5	4.2	6.5	13.0	21.8				
40	1			1.7	2.7	5.3	9.1	14.7	30.2	54.0	84
	2	0.8	1.5	2.5	3.8	7.7	12.7	21.1	43.2	77.5	121
	3	1.0	1.9	3.1	4.8	9.5	16.1	26.0	54.0		
	4	1.2	2.2	3.6	5.6	11.1	18.7	30.0			
50	1				2.4	4.7	8.1	13.0	26.8	47.4	74.5
	2		1.3	2.2	3.4	6.8	11.6	18.7	38.5	69.0	107.0
	3	0.9	1.6	2.8	4.2	8.5	14.3	23.2	47.6	85.5	
	4	1.0	1.9	3.2	4.9	9.9	16.6	26.8	55.5		
75	1						6.6	10.5	21.5	38.6	60.5
	2			1.8	2.8	5.5	9.4	15.2	31.2	55.5	87.0
	3		1.3	2.2	3.4	6.8	11.6	18.7	38.5	69.0	107.0
	4	0.8	1.5	2.6	4.0	7.9	13.6	21.6	44.6	80.5	125.0
100	1							9.0	18.4	32.9	51.5
	2				2.4	4.7	8.1	13.0	26.8	47.4	74.5
	3			1.9	2.9	5.9	10.0	16.1	32.9	56.6	92.5
	4		1.3	2.2	3.4	6.8	11.6	18.7	38.5	69.0	107.0
	1								16.4	29.5	45.9
	2					4.2	7.2	11.6	23.7	42.5	65.6
	3			1.7	2.6	5.2	8.8	14.3	29.4	52.5	82.0
	4		1.2	2.0	3.1	6.1	10.4	16.7	34.1	61.5	96.0

Figure 30. Tonnage Ratings for R-12 Discharge Lines

Cond. Temp.	Suction Temperature										
	0	5	10	15	20	25	30	35	40	45	50
85	1.17	1.15	1.14	1.12	1.11	1.10	1.09	1.08	1.07	1.06	1.05
90	1.14	1.13	1.12	1.10	1.09	1.08	1.07	1.06	1.05	1.04	1.03
95	1.12	1.11	1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01
100	1.10	1.09	1.08	1.07	1.06	1.04	1.03	1.02	1.01	1.00	0.99
105	1.09	1.08	1.07	1.06	1.05	1.03	1.02	1.01	1.00	0.99	0.98
110	1.08	1.07	1.06	1.05	1.03	1.02	1.01	1.00	0.99	0.98	0.98
115	1.07	1.06	1.05	1.03	1.02	1.00	0.99	0.98	0.97	0.96	0.95
120	1.04	1.02	1.01	1.00	0.98	0.97	0.96	0.95	0.94	0.93	0.92
125	1.02	1.01	1.00	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91
130	1.00	0.99	0.98	0.98	0.96	0.95	0.94	0.92	0.91	0.90	0.89

Figure 31. Correction Factors for R-12 Discharge Lines

Refer back to figure 30 and check the line size to be used for 68.8 feet. From figure 30 we find that at 75 feet a 2 1/8-inch line will give 44.6 tons at 4 psi pressure drop or 31.2 tons at 2 psi pressure drop which is sufficient. The next smaller line would result in too large a pressure drop.

Velocity may be checked in the same manner as for the suction lines but using figure 30 for correction factors and figure 26 for velocity.

Correction factor = .99 X 25 = 24.75 tons; velocity for a 2 1/8-inch line is approximately 1700 fpm which is sufficient.

Cond.	Suction Temperature										
Temp	0	5	10	15	20	25	30	35	40	45	50
85	1.43	1.40	1.36	1.33	1.30	1.27	1.24	1.22	1.20	1.18	1.16
90	1.38	1.34	1.30	1.27	1.24	1.21	1.19	1.16	1.14	1.13	1.11
95	1.32	1.28	1.24	1.21	1.18	1.16	1.13	1.11	1.09	1.07	1.06
100	1.27	1.23	1.19	1.16	1.14	1.11	1.09	1.06	1.04	1.03	1.01
105	1.22	1.18	1.15	1.12	1.09	1.06	1.04	1.02	1.00	0.98	0.97
110	1.18	1.14	1.10	1.07	1.05	1.02	1.00	0.98	0.96	0.94	0.93
115	1.14	1.10	1.06	1.04	1.01	0.99	0.96	0.94	0.92	0.91	0.89
120	1.09	1.06	1.03	1.00	0.97	0.95	0.93	0.91	0.89	0.87	0.86
125	1.06	1.03	1.00	0.97	0.94	0.92	0.90	0.88	0.86	0.84	0.83
130	1.03	1.00	0.97	0.94	0.91	0.89	0.87	0.85	0.83	0.81	0.80

Figure 32. Correction Factor for Ventilation of R-12 Discharge Lines

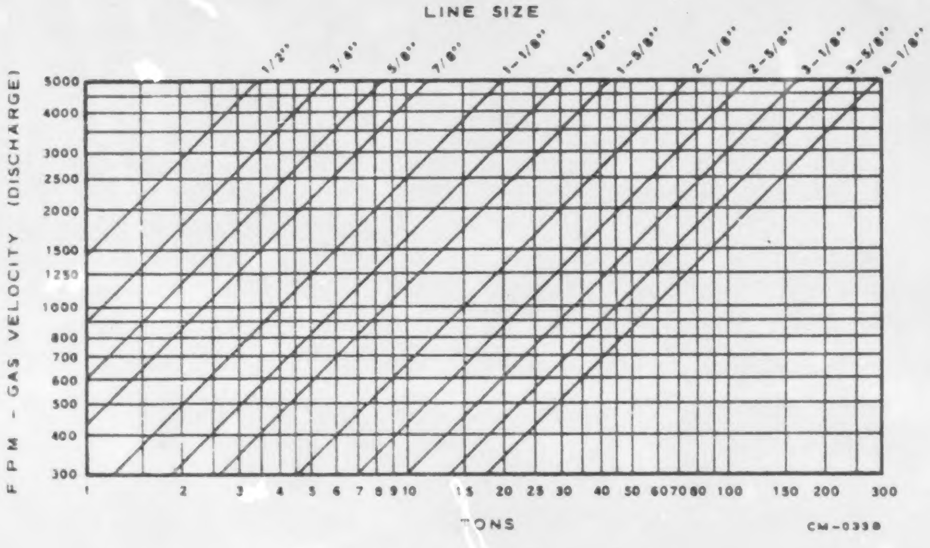


Figure 33. Discharge Gas Velocity

Condenser Drain Lines

This is the line which delivers the liquid refrigerant from the condenser to the receiver. This line must be carefully sized. An undersized line will cause liquid to build up in the condenser, raising the head pressure and decreasing the efficiency and capacity of the system. This line must be as short as possible and the condenser must be installed above the receiver.

SIZING CONDENSER DRAIN LINES. Charts such as the one shown in figure 34 are used in sizing condenser drain lines. This chart also shows the minimum height (in inches) that the condenser must be above the receiver. Where there is a blank space it means this combination of length and pipe size is not recommended.

Length In Feet	O. D. Copper Tubing									
	1/2		5/8		3/4		7/8		1 1/8	
	Tons	Ht.	Tons	Ht.	Tons	Ht.	Tons	Ht.	Tons	Ht.
50	1.8	15	3.3	14	5.3	12	8.0	12	14.5	10
75									13.5	12
100									12.5	15
150									11.5	19
200										

Length In Feet	O. D. Copper Tubing									
	1 3/8		1 5/8		2 1/8		2 5/8		3 1/8	
	Tons	Ht.	Tons	Ht.	Tons	Ht.	Tons	Ht.	Tons	Ht.
50	13.5	9	35.5	8	66.5	7	109	6	165	5
75	22.0	12	33.5	11	62.5	9	104	8	156	7
100	20.0	14	31.0	13	59.0	11	98	9	147	9
150	18.5	17	29.0	16	55.0	14	91	12	138	11
200					50.0	16	84	14	129	13

Figure 34. Tonnage Rating for R-12 Condenser Drain Lines

This chart is for standard conditions of 40° suction and 105° condensing temperatures. Correction factors for other than these conditions are the same as for liquid lines covered in figure 36.

Procedures for sizing this line are the same as the other lines. Velocity does not have to be checked because the oil is easily carried by the liquid refrigerant.

Liquid Lines

This line is the least critical in the system. The refrigerant is in the liquid state so the oil is carried along with no problems. Pressure drop is not critical but must be held at a reasonable value to prevent flash gas in the line. Pressure drop should be held at approximately 2 psi for R-12 and 3 psi for R-22 systems. Velocities should be held below 300 fpm to prevent liquid hammer and noise caused by solenoid valves.

SIZING LIQUID LINES. Figure 35 is an example of a chart used to size liquid lines. This chart is based on 40° suction and 105° condensing temperatures. Correction factors for tonnage are found in figure 36 for other than these conditions.

Length In Feet	Pressure Drop	O. D. Copper Tubing									
		1/2	5/8	3/4	7/8	1 1/8	1 3/8	1 5/8	2 1/8	2 5/8	3 1/8
50	0.3	1.1	2.2	3.7	5.8	11.9	20.7	32.9	69.0	123	195
	0.6	1.7	3.2	5.2	8.5	17.4	30.2	47.9	101	177	
	1.0	2.3	4.0	7.3	11.3	23.1	40.3	63.5			
	2.0	3.3	6.3	10.7	16.5	33.9					
75	0.3	0.9	1.7	2.9	4.7	9.6	16.5	26.3	55.0	100	156
	0.6	1.3	2.6	4.4	6.8	13.9	24.3	38.3	80.5	143	229
	1.0	1.8	3.4	5.8	9.0	18.5	32.2	51.0	106.0	187	
	2.0	2.7	5.0	8.6	13.2	27.2	47.1	74.0			
100	0.3	0.8	1.5	2.5	3.9	8.1	13.8	21.7	46.2	83.5	132
	0.6	1.1	2.2	3.7	5.8	11.9	20.7	32.9	69.0	123.0	195
	1.0	1.5	2.9	5.0	7.7	15.8	27.7	43.4	90.5	161.0	258
	2.0	2.3	4.0	7.3	11.3	23.1	40.3	63.5			
125	0.3	0.7	1.3	2.2	3.4	7.1	12.1	19.4	41.0	74.0	117
	0.6	1.0	1.9	3.2	5.1	10.3	17.8	28.3	59.5	107.0	170
	1.0	1.4	2.6	4.4	6.8	13.0	24.3	38.3	80.5	143.0	229
	2.0	2.0	3.8	6.4	10.0	20.4	35.6	56.5	118.0		
150	0.3	0.6	1.2	2.0	3.2	6.6	11.3	18.0	37.8	69.0	107
	0.6	0.9	1.7	2.9	4.7	9.6	16.5	26.3	55.0	100.0	156
	1.0	1.2	2.3	4.0	6.2	12.6	22.0	34.9	73.0	131.0	207
	2.0	1.8	3.4	5.8	9.0	18.5	32.2	51.0	106.0	187.0	
175	0.3	0.6	1.1	1.8	2.6	5.9	10.1	16.1	34.2	61.5	96.5
	0.6	0.9	1.6	2.7	4.2	8.6	14.8	23.6	49.4	89.5	142
	1.0	1.2	2.1	3.5	5.7	11.6	20.2	32.1	67.0	120.0	190
	2.0	1.7	3.1	5.4	8.3	17.0	29.4	46.6	98.0	172.0	278
200	0.3	0.5	1.0	1.7	2.6	5.5	9.4	14.9	31.9	57.5	90.5
	0.6	0.8	1.5	2.5	3.9	8.1	13.8	21.7	46.2	83.5	132
	1.0	1.0	2.0	3.3	5.2	10.8	18.7	27.6	62.0	112.0	177
	2.0	1.5	2.9	5.0	7.7	15.8	27.7	43.4	90.5	161.0	258
250	0.3	0.5	0.9	1.5	2.3	4.9	8.3	13.3	27.8	51.5	80.5
	0.6	0.7	1.3	2.2	3.4	7.1	12.1	19.4	41.0	74.0	117
	1.0	0.9	1.7	2.9	4.7	9.6	16.5	26.3	55.0	100.0	156
	2.0	1.4	2.6	4.4	6.8	13.9	24.3	38.3	80.5	143.0	229

Figure 35 Tonnage Rating for R-12 Liquid Lines

Cond. Temp.	Suction Temperature										
	0	5	10	15	20	25	30	35	40	45	50
85	.99	.98	.97	.96	.95	.94	.93	.92	.91	.90	.89
90	1.01	1.00	.99	.98	.97	.96	.95	.94	.93	.92	.91
95	1.04	1.03	1.01	1.00	.99	.98	.97	.96	.95	.94	.93
100	1.06	1.05	1.04	1.03	1.02	1.01	1.00	.99	.98	.97	.96
105	1.09	1.08	1.07	1.06	1.04	1.03	1.02	1.01	1.00	.99	.98
110	1.12	1.11	1.10	1.08	1.07	1.06	1.05	1.04	1.03	1.02	1.01
115	1.16	1.15	1.13	1.11	1.10	1.09	1.08	1.07	1.05	1.04	1.03
120	1.19	1.18	1.16	1.15	1.13	1.12	1.11	1.10	1.08	1.07	1.06
125	1.23	1.22	1.20	1.18	1.17	1.15	1.14	1.13	1.11	1.10	1.09
130	1.27	1.25	1.24	1.23	1.21	1.19	1.17	1.16	1.15	1.14	1.12

Figure 36 Correction Factors for R-12 Liquid Lines

The figures omitted on the right side of figure 35 are for velocities above 300 fpm. This chart is used in conjunction with figure 27, Equivalent Length of Valves and Fittings, to compute the line size. Sizing is accomplished in the same manner as the other lines with the exception of the velocity check.

Summary

No matter how large the other parts of a refrigeration system are, its overall capacity is the capacity of the smallest part. A mistake in selection or installation of the piping could easily reduce a 100, 000 Btu unit to a 30, 000 Btu unit. The tables and charts presented contain the necessary data to do the calculations quickly and easily to select the proper size lines for any capacity unit.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, Bracciano
2. Textbook; Trane Refrigeration Manual.

DOMESTIC HERMETIC SYSTEMS

STUDY ASSIGNMENT; Modern Refrigeration and Air Conditioning; Paragraphs 10-1 through 10-15, 8-26 through 8-31, figure 8-75, paragraphs 7-44 through 7-58, chapter 11, and chapter 12.

STUDY NOTES

Paragraph 10-1.

Hermetic units have been on the market since 1926. Once you learn their construction you will find they are as easy to service as open units.

If you will recall the compressor designs studied in earlier units, you will find they are the same ones used in hermetic systems in this unit. Static or natural condensers are popular in some domestic cabinets, while fan-cooled are popular for units having large frozen food compartments.

Paragraph 10-2.

The typical hermetic system may use either of the above condensers. The refrigerant control is usually a capillary tube. It can maintain two temperatures, one in the frozen foods compartment of 5° F or lower, and a temperature of 35° to 45° F in the provisions compartment. Various methods are used to obtain controlled temperatures in each compartment.

Paragraph 10-3, 4.

The no-frost refrigeration system is one of the most popular types of cycles. This system is dependent upon the use of forced air passing over a finned evaporator and then across the food to be cooled or frozen.

Paragraph 10-5, 6.

Domestic units, both the combination freezer and refrigerator or the separate food freezer use either a reciprocating or rotary compressor of hermetic design.

Paragraphs 10-8, 9, 10.

Some forced convection evaporator coils use a fan to control the temperature of the food compartment and the freezer compartment. In this type of arrangement the two systems are separated and insulated from each other. A duct system is used in both compartments to provide a frost-free unit. Some units use a fan in both compartments. The liquid and suction lines of domestic units may be made of copper, steel or alunimum.

Paragraphs 10-11 through 13.

The electrical units on all domestic units are similar. The main wiring consists of a plug-in cord, thermostat, relay and motor. The relay is usually used as a junction box, the thermostat is connected in series with the motor, the light switch and light are parallel with the motor. If the condenser is of forced convection, the motor is in series with the thermostat and parallel with the compressor motor.

Go over the wiring diagrams in the textbook carefully. If you ever have to replace wiring keep the same color coding if possible.

Paragraphs 8-26 through 8-31 and figure 8-75.

Here is valuable information you should know. Careful study of this material and paragraphs 7-44 through 7-58 will enable you to overcome the many difficulties you may encounter in servicing electrical components.

Chapter 11.

Today after years of development and research, the domestic systems cabinet is an artistic and technologically developed appliance. It has a minimum of waste space inside, it is a marvel of reliability, the hardware never seems to wear out. The exterior is attractive and the interior places items readily at hand. Although the material presented is quite lengthy, it will be of great benefit to you in the proper maintenance of these units.

Paragraph 12-1.

Good workmanship can only be done with tools of good quality which are in good condition. These tools must be used in the proper way.

Paragraphs 12-2 through 6.

It is important that you become familiar with the units you will be called upon to service. Most refrigerators have a data plate and wiring diagram on the back of the cabinet. The nameplate usually contains the following information;

1. Manufacturer's name

2. Type and amount of refrigerant

3. Model number

4. Serial number

5. Electrical data

When servicing, many times it will not be possible to obtain an original part. Relays, thermostats, capacitors, etc. all usually have identifying numbers. Cross-reference manuals printed by manufacturers are an invaluable aid for making substitutions.

Paragraphs 12-7 through 9.

One of the most important things to remember when you are looking for trouble in a system, is to use a systematic approach and analysis. Train yourself to do trouble-shooting slowly and thoroughly. Trial and error, hit or miss methods waste time and money. Study the troubleshooting chart carefully. It gives many typical complaints and what should be done for each.

Paragraphs 12-10 through 17.

These paragraphs cover many of the service operations to be done on domestic systems, such as adding refrigerant, oil, driers, etc. Also covered are component replacement and repair and the methods of gaining access to hermetic systems.

Paragraphs 12-18 through 12-47.

Carefully study the material presented. It provides the guidelines you will need, to perform the many and varied services of the domestic refrigeration portion of your specialty.

SUPPLEMENTARY INFORMATION

CONSTRUCTION FEATURES OF DOMESTIC REFRIGERATORS

Insulation

Any substance that retards the flow of heat may be used for insulating purposes. A great number of substances have been used for insulation in domestic refrigerators. Fiberglass and foamed plastic are the most widely used today.

Vapor Barrier

Condensation of moisture occurs on any surface that is at a temperature below the dewpoint of the surrounding air. However, we must keep moisture out of the insulated space between the inner and outer shell. This is particularly important around the freezing section. Several substances are used for this, but the most important one in domestic boxes is plastic. The plastic is placed in such a way as to stop the water vapor in the air from getting to the cold surface. The suction line is often insulated with an insulating tape. The holes where the refrigerant and electrical lines go through the box are usually stuffed full of a soft, putty like substance known as permagum. An odorless tar is often spread over an area or surface to prevent vapor transmission.

Door

The modern refrigerator may have either one or two doors. These doors are designed to cover the entire front of the refrigerator. The inside of the door may be recessed for small shelves. The inside panel is made of plastic. Since the panel is of lightweight material, it aids in reducing the total weight of the door. The plastic panel is designed to aid in keeping the door from warping.

Breaker Strip

The breaker strips, see figure 37, are pieces of plastic that cover the space between the inner and outer shells. Each manufacturer installs the breaker strips in different manner. Some use screws, some use clamps, while others snap them in. Since breaker strips are made of plastic, they become brittle when cold and will break easily. Before attempting to remove a breaker strip allow it to warm. Before installing a cold breaker strip, dip it in warm water. This will make it soft and pliable and reduce the possibility of breakage.

Mullion Heaters

The mullion heater, see figure 37, is a strand of high resistance heater wire attached to a strip of aluminum foil. The mullion heater is installed around the doors under the breaker strips. When the box is plugged in, electricity is applied to the mullion heater. The heater gets hot, and adds enough heat to the area around the door to reduce sweating or freezing. A mullion heater is particularly important around the door to the freezer. If the mullion heater fails, moisture will condense around the door and the door will freeze shut.

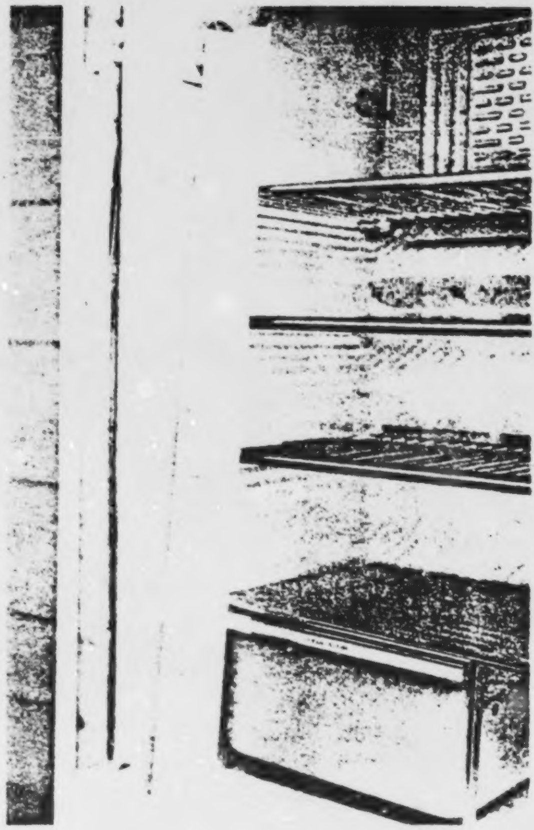


Figure 37. Mullion Heater and Breaker Strip

Condensers

The condensers in domestic refrigerators are usually made of steel and are one of the following types: plate finned (forced convection), coiled tubing with a wire frame, and coiled tubing mounted on the inside of the refrigerator shell. In the past few years, several manufacturers have built the condenser as an integral part of the outside wall. From a visual standpoint, it appears that the unit does not have a condenser. However, let the unit operate for 30 minutes, and then put your hand on the outside of the box. The hot area will indicate the exact location of the condenser.

Refrigerant Control

All modern domestic refrigerators use a capillary tube refrigerant control. This control is simple, economical, and allows the use of a low torque motor. One end of the capillary tube is attached to the bottom of the condenser. There may be a strainer installed between the condenser and capillary tube. The capillary tube is soldered to the suction line, and it terminates in an expansion chamber at the top of the evaporator.

PRINCIPLES OF OPERATION. Liquid refrigerant with a pressure of 120 to 140 psig and a temperature of 90 to 120°F enters the capillary tube. (Pressures and temperatures are approximations.) As the liquid travels through the capillary tube, its pressure is reduced by the resistance to flow in the tubing. At the same time, its temperature is being reduced by the cold suction line. These two forces continue to act on the liquid refrigerant as it proceeds through the capillary tube. However, the pressure is reduced (comparatively) faster than the temperature. At some point (usually within the last 12 to 24 inches) the pressure of the liquid refrigerant "flashes" or boils. The vapor occupies more space than the liquid so the pressure is again increased. The temperature of the refrigerant is decreased by both the flashing of the liquid and by the contact with the cold suction line. The point where the flashing first occurs at the end of the capillary tube is known as "vaporlock."

All capillary tubes have a vaporlock. The length of the vaporlock depends on a combination of the following factors: (1) condensing temperature, (2) condensing pressure, (3) amount of subcooling of the liquid in the condenser, (4) temperature of the suction, (5) pressure difference between the low and high side, and (6) the length and diameter of the capillary tube.

Thermostat

The thermostat, see figure 38, used on normal refrigerators is a factory adjusted item with a set differential of approximately 13° and an adjustable range. At the highest setting the evaporator temperature may be 10° and at the lowest setting -20°F. The thermostat is usually installed in a location convenient to the user with the thermal bulb clamped to the evaporator.

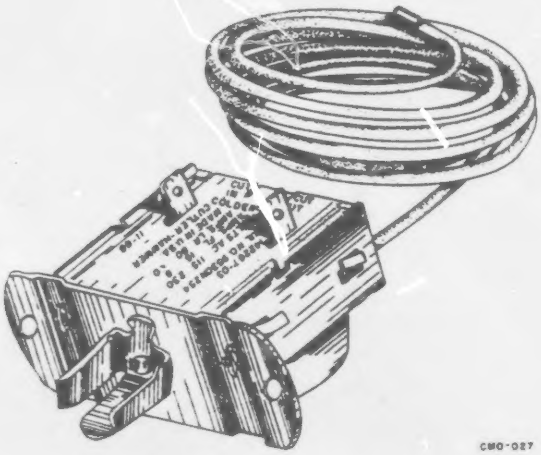


Figure 38. Thermostat

Evaporator

The evaporators used in domestic refrigerators must be rugged, functional, and attractive. Frosting-type refrigerators usually use a flooded-type evaporator or a plate with aluminum tubing attached to the back. Very often you will find a refrigerator that uses a plate evaporator with a preformed refrigerant coil in the freezer section and a regular flooded type evaporator in the refrigerator section. These plate-type evaporators are normally made of aluminum. Home freezers often use an evaporator that is composed of coiled aluminum tubing crisscrossed with steel or aluminum wire.

Door Gasket

Domestic refrigerators have a synthetic rubber or flexible plastic gasket around the door. This gasket or seal is designed to make an airtight seal between the door and the refrigerator body. Door seals usually last from five to seven years. It is always best to replace door seals with an exact like item. However, this is not always possible. Sometimes you will find it necessary to use a general replacement seal.

COLD STORAGE--REFRIGERATOR COMBINATIONS

During the initial development of the domestic refrigerators, the freezing section was very small. It would hold two or three ice-cube trays and that was about all. The customer demanded more and more freezer space until some boxes are one-third freezer space. The freezer space must be maintained at approximately 0°F while the refrigerator section is approximately 40 to 50°F. Several methods have been employed to maintain these two temperature ranges within the same box.

Two-Temperature Refrigerators

The air spillover, see figure 39, is the oldest method used to maintain two different temperatures. The cold air that flows or spills over the frozen food compartment cools the regular refrigerator space. This system has disadvantages. During periods of light usage, the temperature of the refrigerator space will become too cold. During the periods of heavy usage, the temperature will be too high, and there will be an excessive buildup of frost on the evaporator.

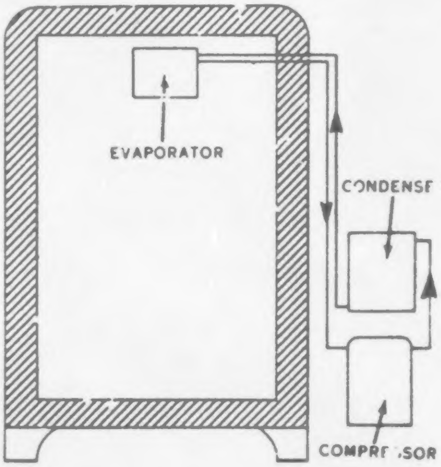


Figure 39. Air Spillover

The refrigerant spillover is the second type of two-temperature refrigerator, see figure 40. In this system the tubing, evaporator size, and the refrigerant charge are very critical. The liquid refrigerant goes to the coldest evaporator first. If this area needs refrigeration, all the refrigerant is vaporized, and the vapor is superheated in the second evaporator before going to the compressor. When the first evaporator is satisfied, the liquid will spill over into the second evaporator and be vaporized there. An accumulator at the end of the coldest evaporator aids in keeping the refrigerant from spilling over too soon.

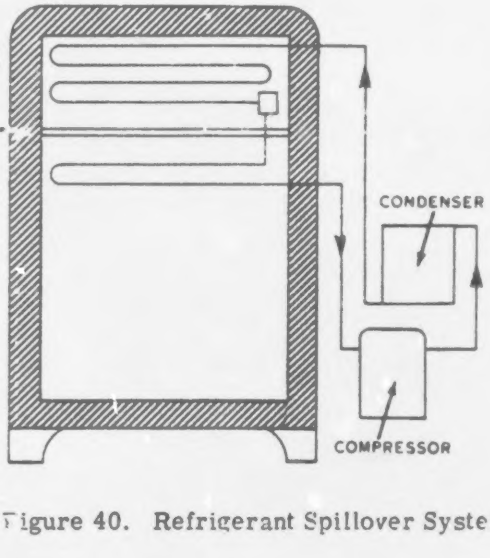


Figure 40. Refrigerant Spillover System

The metered chilled air system is used on modern "no-frost" refrigerators. It utilizes a finned, forced convection evaporator that is located in the frozen food compartment, see figure 41. A fan forces the air over the evaporator coil and over the food in the frozen food compartment. A critically sized duct runs from the evaporator to the fresh food compartment. Therefore, a metered amount of cold air is forced through this duct into the fresh food compartment. This air is very cold and is usually directed toward the top or sides of the box. If this cold air is allowed to strike a product directly, the product will freeze. Small holes permit the air to return from the fresh food compartment to the freezer compartment. It is necessary to use some form of automatic defrost on this system.

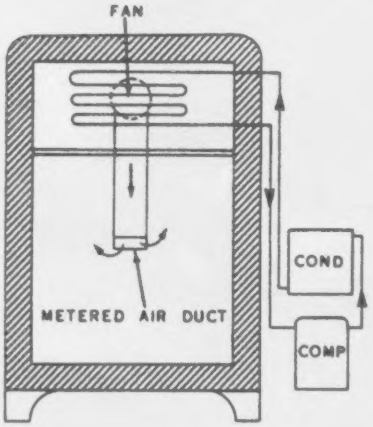

FAN
COND
METERED AIR DUCT
COMP

Figure 41. Metered Air System

Since the thermal bulb is not attached to the evaporator, it senses air temperature only. Most manufacturers place the thermal bulb in the freezer compartment; however, others place it in the fresh food compartment.

Airflow

The freezer air is drawn into the return air duct, see figure 42, at the front of the freezer. It passes to the rear between the divider and freezer bottom. It is then drawn upward through the evaporator and discharged into the freezer section. The sensing element of the thermostat is located at the rear of the freezer air return duct.

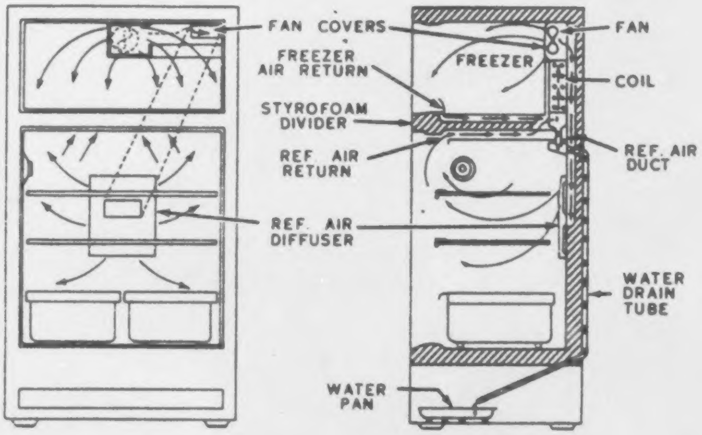

FAN COVERS
FREEZER AIR RETURN
STYROFOAM DIVIDER
REF. AIR RETURN
REF. AIR DIFFUSER
FREEZER
FAN
COIL
REF. AIR DUCT
WATER DRAIN TUBE
WATER PAN

Figure 42. Airflow in a No-Frost Refrigerator

The refrigerator air is drawn into the refrigerator air return duct at the top and front of the refrigerator section. It passes to the rear of the section between the styrofoam divider and the top of the refrigerator section. It is drawn upward through the cooling coil and discharged into the fan cover by the fan. Part of the air that is discharged into the fan cover is directed into the refrigerator air duct, which is mounted on the insulation side of the liner. The air then passes down the duct and enters the refrigerator section through the air diffusers, which distributes the air throughout the refrigerator section. The amount of air entering the refrigerator is carefully balanced with the amount of air entering the freezer to achieve proper temperature in both sections.

HERMETIC COMPRESSORS GENERAL

Modern domestic refrigerators use a hermetic compressor. These compressors have some outstanding advantages over open-type units. One advantage is that the compressor motor assembly is much lighter and somewhat stronger. Strong foundations for mounting the heavy open-type compressors are completely eliminated. The faster operational speeds reduce the need for size in the hermetic compressors. The motor and compressor are connected to the same shaft and are positioned as close together as possible. This feature eliminates the bulkiness of the open-style system where the motor and compressor were set apart and driven by V-belts. The most important advantage of the hermetic unit is that the ever troublesome shaft seal is completely eliminated. The elimination of the shaft seal was the prime reason for the hermetic-type compressor.

The hermetic design allows the motor and compressor to be enclosed in a housing that is airtight. Moisture, dust, grease, and all foreign particles are sealed out which allow the assembly to operate free of these disturbing elements. As a result, the unit functions at full rated capacity for a longer period of time.

Hermetic compressors operate more quietly than the open style. Any sound originating in the compressor or motor must first pass through the refrigerant vapor within the housing. It must then be transmitted through the steel casing before it can reach the outer area. Therefore, the noise is greatly reduced. Vibrations are almost eliminated due to the rapid cycling of the high speed unit which tends to smooth out larger pulsations. The complete assembly is usually mounted on springs or rubber shock absorbers that dampen out any vibrations that might originate from the assembly.

As a unit, all the advantages previously discussed indirectly result in an efficiency that makes the hermetic unit superior to other types.

Hermetic units have two main disadvantages. They are not easily serviced in the field; and, in case of motor burnout, the complete system becomes contaminated.

Types of Hermetic Compressors

There are two types of hermetic compressors; the reciprocating and the rotary. The reciprocating compressor is the most popular compression system for all sizes of hermetic units. However, it has more parts and, therefore, costs more to manufacture than the rotary type. Except in very small sizes, the rotary compressor is not as efficient as the reciprocating, therefore, the principal use of rotary compressors is in domestic refrigerators.

Classification of Hermetic Compressors

Hermetic compressors are normally classified under one of the following main headings:

Accessible (semihermetic). These compressors are normally fitted with service valves. They can be serviced in the field to the extent of replacing the valves, valve plates, pistons, rods, and rewinding the motor.

Sealed (internally shock-mounted). Internally shock-mounted compressors need very little external shock mounting. A small rubber grommet around the mounting bolt is necessary.

Sealed (externally shock-mounted). The compressors must be spring supported or mounted on large mounting pads.

Design Characteristics

Reciprocating hermetic compressors have different design characterisitcs. These characteristics and some pertinent information concerning them are listed below. The crankshaft is mounted either vertically or horizontally. There are also three different shaft designs: cranks, eccentrics, and the scotch yoke.

METHODS OF LUBRICATION. Hermetic compressors are lubricated by one of the following methods: splash, flood, or forced feed systems. The splash system is used almost universally in fractional-horsepower units. The bearing clearance must be large enough so that the oil can enter the bearing easily. The large bearing clearances plus the splashing effect of the dippers in the oil cause these compressors to produce a little more noise than other types. The splashing at high speed induces oil foaming and pumping. The flooded system includes all types of devices that lift the oil up and allows it to flood (run down) over the bearings, pins, and surface areas. The oil is not agitated as violently as with the splash system which results in quieter operation and less oil pumping. This system is often used in air-conditioning compressors. The forced feed system uses a pump to force the oil through drilled passages to the bearings. The bearings can be closely fitted resulting in very quiet operation. This type of system is used in large high-speed compressors.

MOTOR COOLING. The cooler an electric motor operates, the more power it will produce. Therefore, it is imperative that the motor in a hermetic compressor be kept as cool as possible. Hermetic compressors are normally cooled by one or more of the following methods: suction gas cooling, air cooling, or oil cooling. The suction gas is directed around the motor before it goes to the cylinder. There may be a fan inside the shell that aids in forcing the cold gas around the motor. Air is used to cool hermetic compressors by both natural and forced convection. Some compressors have external fins that aid in heat transfer. Some domestic refrigerators have a separate oil cooler circuit that cools the oil in the compressor. This is usually accomplished by passing the discharge gas through an oil cooler circuit, desuperheating it, and then returning it to the compressor where it picks up heat from the oil before going to the condenser, see figure 43.

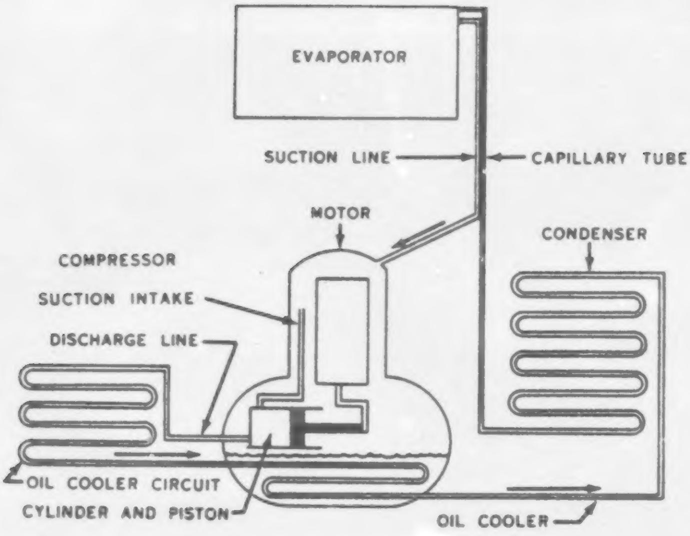

EVAPORATOR
SUCTION LINE
CAPILLARY TUBE
MOTOR
CONDENSER
COMPRESSOR
SUCTION INTAKE
DISCHARGE LINE
OIL COOLER CIRCUIT
CYLINDER AND PISTON
OIL COOLER

Figure 43. Oil Cooler Circuit

Terminal Arrangement

Hermetic compressors employ two types of single-phase motors, the split phase and the capacitor start. On the housing containing the motor and compressor, you will find three terminals which connect to the start and run windings. These terminals are commonly referred to as the run, start, and common terminals. Some of the possible terminal arrangements are illustrated in figure 44.

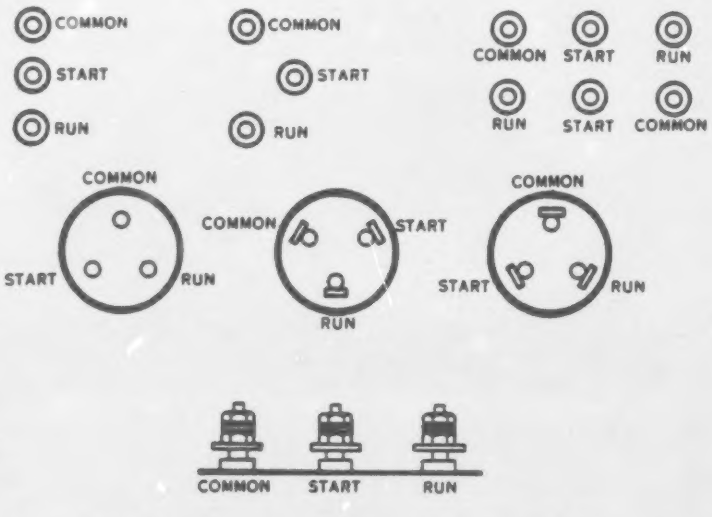

COMMON
START
RUN
COMMON
START
RUN
COMMON
START
RUN
RUN
START
COMMON
COMMON
START
RUN
COMMON
START
RUN
COMMON
START
RUN
COMMON
START
RUN

Figure 44. Possible Terminal Arrangements

One major manufacturer of hermetic compressors always installs the terminals in the order: common, start, and run. The terminals are then read just as you read a book. See figure 44. Start at the top left-hand corner and read each line from left to right.

Sometimes the compressor terminal arrangement is not known. Then it becomes a problem to determine just which is the common, start, and run. To be able to correctly wire the system or replace the starting relay, the terminals must be known. One method is to measure the resistance across the terminals. Then by deduction, find the R, S, and C terminals.

PROCEDURE. The first step is to number the terminals. The second step is to measure the resistance across the terminals. This requires three readings, one across each set of terminals, see figure 45.

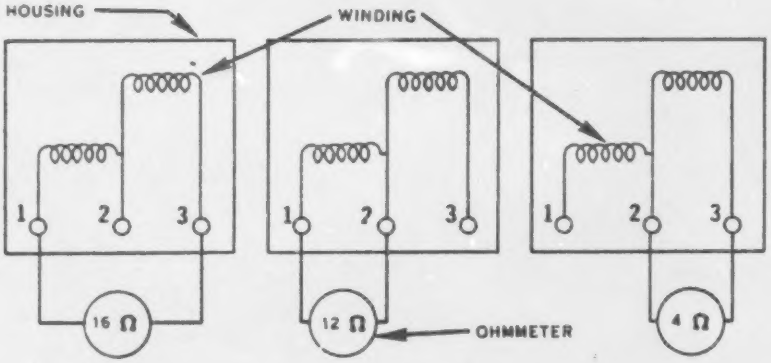


Figure 45. Taking Readings Across Terminals

The highest reading obtained will indicate the start and run windings because it is a measure of the resistance in both windings. This will immediately identify the other terminal as being the common. The next higher reading will identify the start and the lower reading will identify the run terminal.

Use the following procedure, in the sequence listed, to measure the resistance: Use an ohmmeter to take a reading between terminals 1 and 3, see figure 45. In this case it is 16 ohms. Take a second reading between terminals 1 and 2. In this case it is 12 ohms. Take a third reading between terminals 2 and 3. In this case it is 4 ohms.

Terminal readings:

1 and 3 = 16
1 and 2 = 12
2 and 3 = 4

The highest reading obtained was between terminals 1 and 3 so we can say that these terminals are the start and run terminals. This means that terminal 2 has to be the common terminal. To determine which is the start and run terminals, observe the reading from the common terminal (terminal 2) to each of the other terminals. The highest of these two readings indicates terminal 1 is the start and the lower reading to terminal 3 indicates it is the run terminal.

This procedure also tells you if your motor windings are good. The two lower readings obtained (12 and 4) should equal the larger reading (16). If they don't it means the windings are cross-shorted and the compressor motor is not good.

STARTING RELAYS

A hermetic compressor normally uses an induction motor with two windings: a starting winding and a running winding. This arrangement requires some type of switch to automatically disconnect the starting winding as soon as the motor reaches approximately 3/4 of rated speed. This automatic function is performed by a switch known as a starting relay.

Current Relay (General)

Current relays operate on the principle that current draw of a motor is always highest at slow speed. The current relay, see figure 46, is in reality a normally open solenoid operated switch. During the off cycle, gravity holds the switch open. At the moment the unit turns on, current flows through the running winding and the coil in the solenoid. Since the motor is at rest, the current flow is very high.

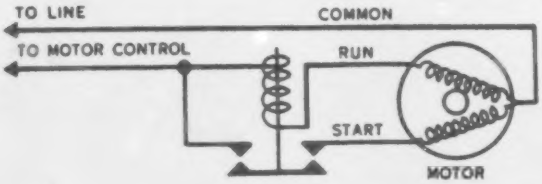


Figure 46. Current Relay Schematic

The coil is heavily magnetized and overcomes the force of gravity. The contact points move up and complete the circuit to the start winding. (Current is already flowing through the run winding.) With current flowing through both the run and start windings, the motor develops enough torque to start the compressor.

When the motor reaches approximately three-quarter of rated speed, the counter emf (electromotive force) produced in the motor reduces the flow of current. The coil is now demagnetized, and the force of gravity opens the solenoid switch and stops the flow of current to the start windings. The motor continues to operate on the run windings.

ADVANTAGES. Current relays are smaller and cheaper than potential relays.

DISADVANTAGES. The points open at high current flow resulting in considerable electrical arcing, causing pitting of the points.

APPLICATION. Current relays are used on small low torque motors. Current relays are usually used on fractional horsepower units that use a capillary tube refrigerant control. These relays must be installed so that gravity will hold the points in the open position.

Type I Current Relay

A wiring diagram of a water cooler using an open coil current relay is illustrated in figure 47. The solid lines are the electrical wiring connections. The dashed lines are the internal connections between the compressor terminals and motor windings. Study this diagram until you understand it thoroughly. Locate and identify each component and electrical connection illustrated in this diagram.

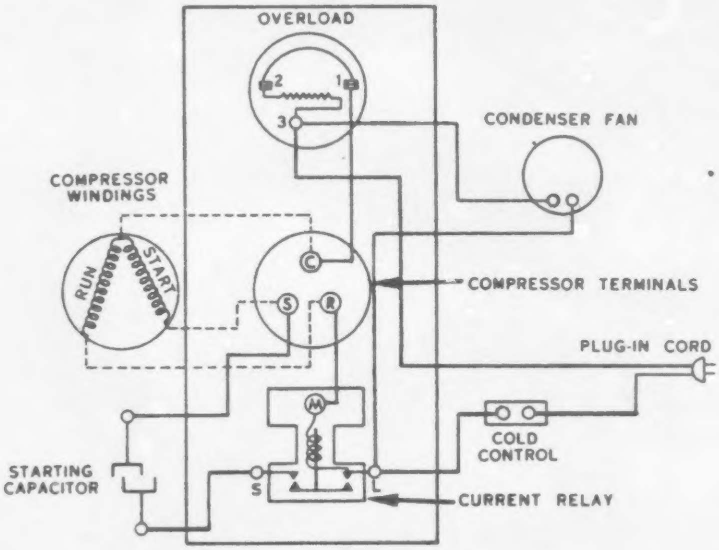

OVERLOAD
2
1
3
CONDENSER FAN
COMPRESSOR WINDINGS
RUN
START
C
S
R
COMPRESSOR TERMINALS
PLUG-IN CORD
M
COLD CONTROL
STARTING CAPACITOR
S
L
CURRENT RELAY

Figure 47. Wiring Diagram (Open Coil Relay)

OPERATION. When the thermostat closes, current flows from the plug-in cord to terminal "L" on the relay. At this moment, two circuits are completed.

Condenser Fan Circuit. Current flows from terminal "L" through the condenser fan to terminal 3 on the overload. From terminal 3 the current returns to the plug-in cord. The condenser fan is now operating.

Compressor Circuit. From terminal "L" the current flows through the coil in the relay to terminal "M." From terminal "M" the current flows to the compressor terminal "R" through the run windings to compressor terminal "C." From terminal C" current flows through the overload and back to the plug-in cord. The high current flowing through the motor magnetizes the coil in the relay and completes the circuit from terminal "L" to terminal "S." Current flows from terminal "S" through the start capacitor to compressor terminal "S." From terminal "S" current flows through the start winding to compressor terminal "C." From terminal "C" the current flows through the overload and back to the plug-in cord. At this moment the motor starts. Then current flow through the coil is reduced allowing the solenoid switch to open. Now the motor operates on the run winding only. All the current going through the compressor windings must pass through the overload. However the current going to the condenser fan does not go through either the relay or the overload.

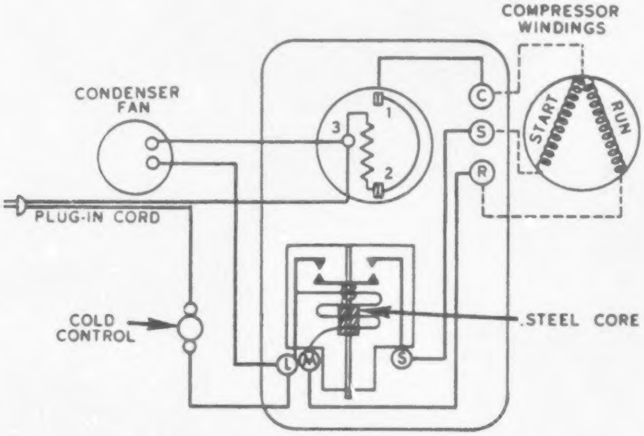


Figure 48 Wiring Diagram (Enclosed Coil Relay)

Type II Current Relay

Figure 48 illustrates an enclosed coil current relay. This relay differs from the open coil in three ways: (1) the complete relay is enclosed, (2) the coil is below the contact points instead of above them, and (3) the relay contains a movable steel core.

Study the wiring diagram until you are thoroughly familiar with it. The electrical connection on most of these relays come with the run and start leads attached.

OPERATION. The operation of the Type II relay is very much like the Type I relay with the following exception: The contact bar rests on a very light spring, which in turn rests on a steel core. This whole contact assembly is mounted around but not attached to a stationary bar that runs completely through the relay. The contact assembly is free to move up and down. Normally it is in the down position (due to gravity) and the points are open. At the startup the coil becomes highly magnetized. The steel core moves up pushing the spring and contact bar up closing the contact points. When the motor reaches approximately two-thirds to three-quarters of its rated rpm, the coil is demagnetized, the core drops down, and opens the contact points.

Hot Wire and Thermal Relays

There are two types of relays that work on the principle that it takes time for electrical current to heat a conductor and that heat makes metal expand or move. These relays are used in the same type of application as current relays.

HOT WIRE RELAY. This relay operates on the principle that electricity passing through a conductor produces heat and makes metal expand. Figure 49 illustrates a typical hot wire relay installation.

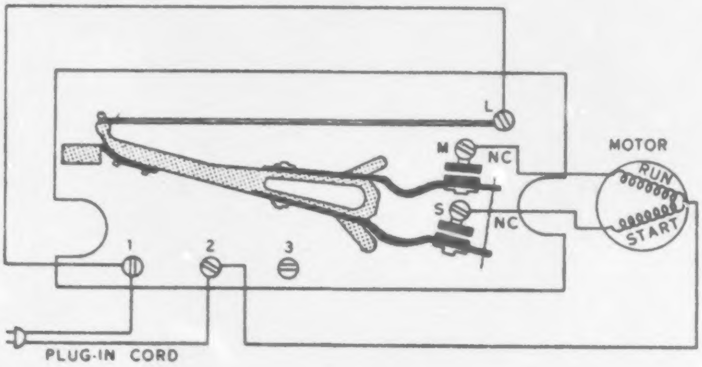


Figure 49 Hot Wire Relay

The contact points at M and S are normally closed. When the motor control closes, current flows from the line to terminal 1 and up to terminal L. The current flows from terminal L down the hot wire and through internal mechanism, to the M and S contact points. From there it flows through both the run and start windings and out the common terminal to the line. At this moment current is running through both the run and start windings and the motor starts. At startup, there is a large current flow through the hot wire. The hot wire gets hot and expands. This small increase in length allows the internal mechanism to move enough to open the start contact points. This stops the flow of current through the start windings but the motor continues to operate on the run windings. If the current flow through the run windings becomes excessive, the hot wire will again increase in length, and the internal mechanism will move enough to open M contact points and stop the motor.

Hot wire relays have been used on a great number of domestic refrigerators in the past. However, at the present time most manufacturers are using the current relay because it is smaller, and less troublesome.

THERMAL RELAY. The thermal relay, see figure 50, operates on the principle that a bimetal element will bend when heated. With the thermostat open, both contact points are closed. When the thermostat closes, current comes in terminal L and goes out both terminals M and S. The compressor is at rest, so there is a large current flow through the heater and the left-hand bimetal strip. The bimetal strip gets hot and moves to the right, opening the contact points. The start windings are cut out of the circuit, and the compressor continues to operate on the run windings. There is enough current going through the run windings to keep the heater hot enough to prevent the bimetal strip from returning to its original position. When the thermostat opens, the heater will cool off, and the bimetal strip will return to its original position.

The overload protection is provided by the right-hand bimetal strip. During normal operation, the right-hand contact points are closed. High current flow will heat the bimetal strip, and it will move to the left, opening the contact points. As soon as the bimetal strip cools off, it will return to its original position.

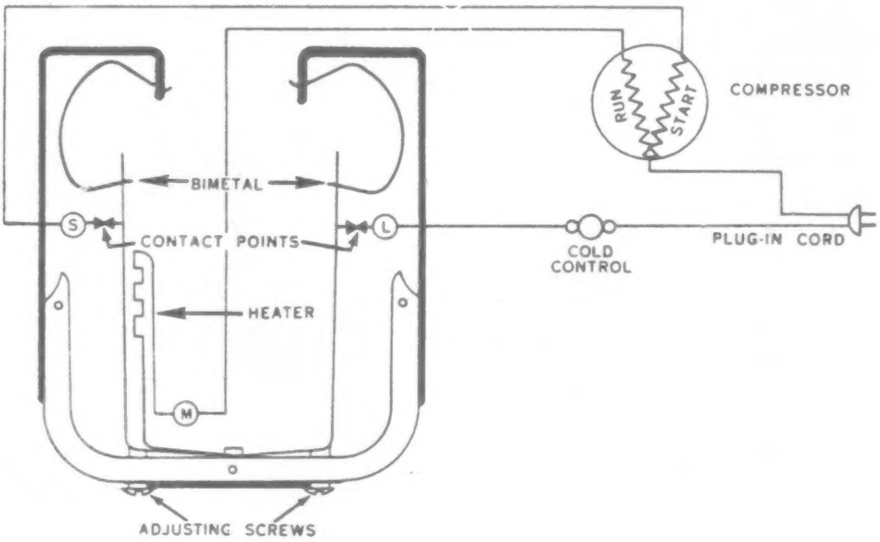


Figure 50. Thermal Relay

Potential Relay

When a motor is operating, the run winding induces a voltage into the start winding. The potential relay, see figure 51, uses this induced voltage to open the points in the relay when the motor reaches approximately two-thirds to three-quarters of rated rpm.

When the compressor is on the off cycle, the contact points in the relay are closed. When the motor control closes, see figure 51, electricity flows from the line to terminal 4. From terminal 4, current flows simultaneously through three individual circuits: the run circuit, start circuit, and condenser fan circuit.

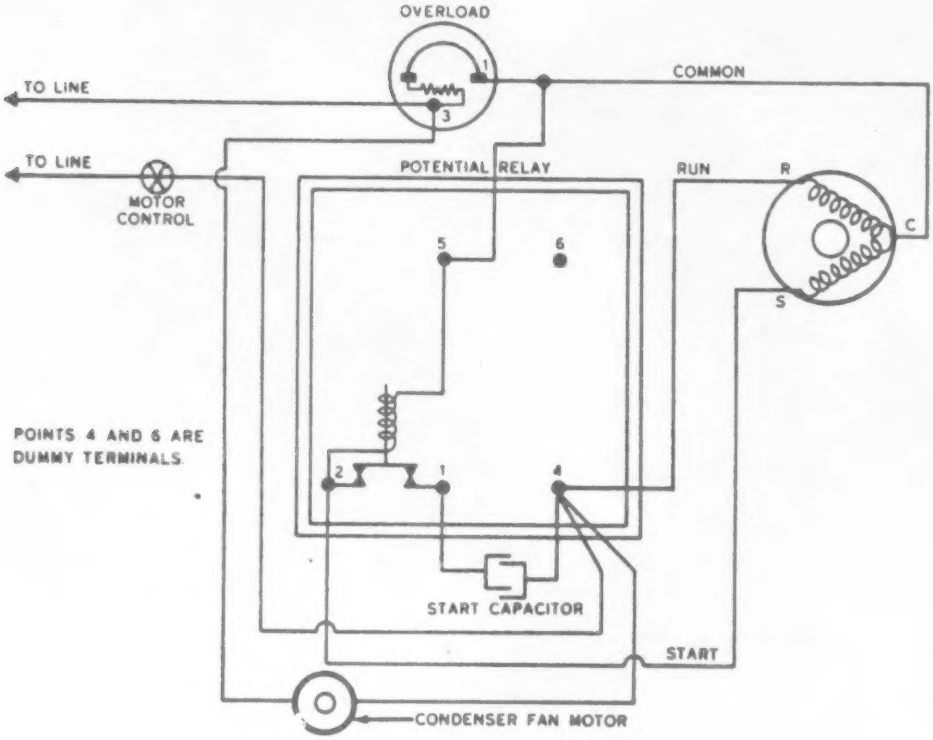

OVERLOAD
TO LINE
1
3
COMMON
TO LINE
MOTOR CONTROL
POTENTIAL RELAY
RUN
R
C
S
5
6
POINTS 4 AND 6 ARE DUMMY TERMINALS
2
1
4
START CAPACITOR
START
CONDENSER FAN MOTOR

Figure 51. Potential Relay

RUN CIRCUIT. Current flows from terminal 4 through the run winding, out the common terminal, through the overload and back to the line..

START CIRCUIT. Current flows from terminal 4 through the start capacitor to terminal 1. From terminal 1 the current flows through the contact points (that are spring-loaded closed) to terminal 2. The coil in the solenoid consists of several hundred turns of very fine wire; therefore, it has a very high resistance. There is much less resistance in the start windings, so the current takes the path of least resistance and goes through the start windings and out the common terminals to the line.

CONDENSER FAN CIRCUIT. Current flows from terminal 4 through the condenser fan motor, to terminal 3 on the overload and back to the line.

When the motor control closes, the compressor motor starts because current is flowing through both the start and run winding. When the motor reaches approximately two-thirds to three-quarters rated rpm, the run winding induces a voltage into the start winding. This induced voltage is in opposition to the applied voltage. Therefore, the resistance in the start winding is increased. As soon as the resistance in the start winding exceeds the resistance in the relay coil, current will flow through the coil. The current flow magnetizes the coil and opens the contact points. Current continues to flow through the run winding, and the motor continues to operate. When the contact points open, the flow of applied current through the start winding stops. However, the run winding continues to induce a voltage into the start windings. This induced voltage causes current to flow from the start winding (which is acting as a secondary winding on a step-up transformer) through the coil and common terminal back to the start winding.

In reality, there is a complete independent electrical circuit that holds the contact points open while the motor is operating. This circuit starts with the induced voltage at the start windings, (which acts as a power source) goes to terminal 2, through the coil (which acts as a unit of resistance) and out to the terminals. From terminal 5, the current flows through the common terminal back to the start winding, figure 52.

ADVANTAGES. The points open during low current flow thus reducing electrical arcing.

DISADVANTAGES. Potential relays are larger and cost more than the current relays.

APPLICATION. Systems using high torque motors and automatic or thermostatic expansion valves. This relay is position sensitive to the degree that it must be mounted in the same manner as the original factory application.

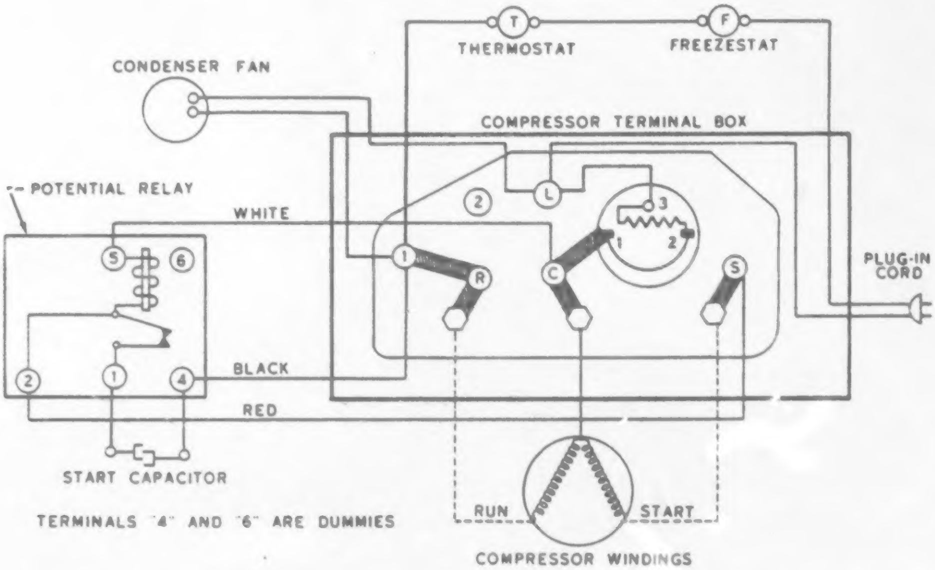


Figure 52. Potential Relay Wiring Diagram

THERMAL OVERLOADS

All hermetic compressors must have some protection against overloads and voltage surges. Hot wire relays use the tension of the hot wire for this purpose. Current and potential relays require an external means of motor protection. This protection is provided by a unit known as the thermal or motor overload. This thermal overload, see figure 53, consists of a round bakelite casing containing a bimetal disc and a heater wire. The protector is usually connected in the common lead going to the compressor. All current going to the compressor must pass through the protector.

The heater is designed to carry a given amount of current without getting hot. If the motor becomes overloaded and draws too much current the heater will get hot. The heat affects the bimetal disc and causes it to break the circuit. As soon as the heater cools off the bimetal disc will move back into position and complete the circuit again. This cycle will continue to repeat itself until the high current flow through the motor is reduced.

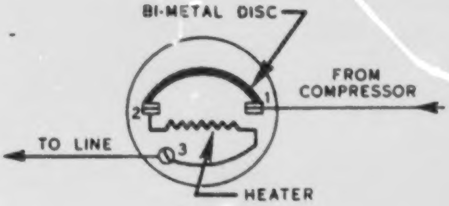


Figure 53. Thermal Overload

Thermal overloads cause very little trouble. However, they should always be replaced when replacing the starting relay. If a thermal overload appears to be faulty, it can be checked by the following procedures: (1) Unplug the unit and install a jumper wire across the thermal overload, (2) plug in the unit and turn it on, (3) if the unit operates, check the current flow through the jumper wire, (4) if the current flow is not excessive, the thermal overload is faulty and must be replaced, and (5) if the current flow is excessive, unplug the unit immediately and check for the cause of high current flow.

Some modern hermetic compressors come equipped with a bimetal thermal disc installed in the winding of the motor. This thermal disc aids in reducing motor burn-outs because it senses the temperature of the motor windings. The internal bimetal disc does not eliminate the need for an external thermal overload. Only the power going to the compressor goes through the thermal overload. The condenser fan or any other unit must be connected on the line side of the thermal overload.

SERVICING HERMETIC COMPRESSORS

Starting a Hermetic Compressor

It is possible to start a hermetically-sealed compressor without using a start relay. Connect a plug-in cord to the common and run terminals as illustrated in figure 54. Momentarily, place an insulated jumper wire between the run and start terminals. The jumper wire must be removed as soon as the motor starts.

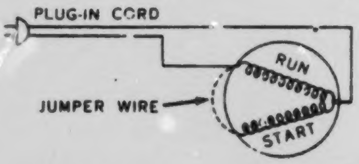


Figure 54. Jumper Wire System

A schematic of a pushbutton type start cord is shown in figure 55. These cords come equipped with a normal plug-in on one end and three alligator clips (for the attachment to terminals on the compressor) on the other end. The pushbutton switch is spring-loaded to the OPEN position.

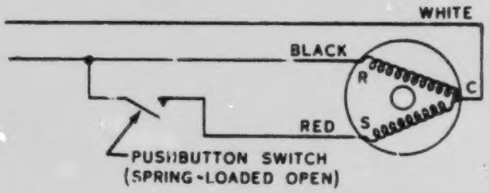


Figure 55. Schematic Pushbutton Starter Cord

The main purpose of the starting cord is to check a malfunctioning starting relay. If the compressor will not start and you suspect that the relay is faulty, proceed in the following sequence to locate the trouble:

- Check the power at the relay. If there is electrical power to the relay, proceed to the next step.
- Unplug the unit.
- Remove the relay.
- Install the white alligator clip on the common terminal.
- Install the black alligator clip on the run terminal.
- Install the red alligator clip on the start terminal
- Plug in the start cord.
- Push the start button.

CAUTION: The start button must not be held down more than a few seconds. If the compressor starts, the starting relay is faulty and must be replaced.

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Motor Starter Analyzer

There are several manufacturers that produce test instruments known as motor start analyzers, see figure 56. These instruments differ a little from one manufacturer to another, but they all have the same purpose: starting and analyzing hermetic compressors.

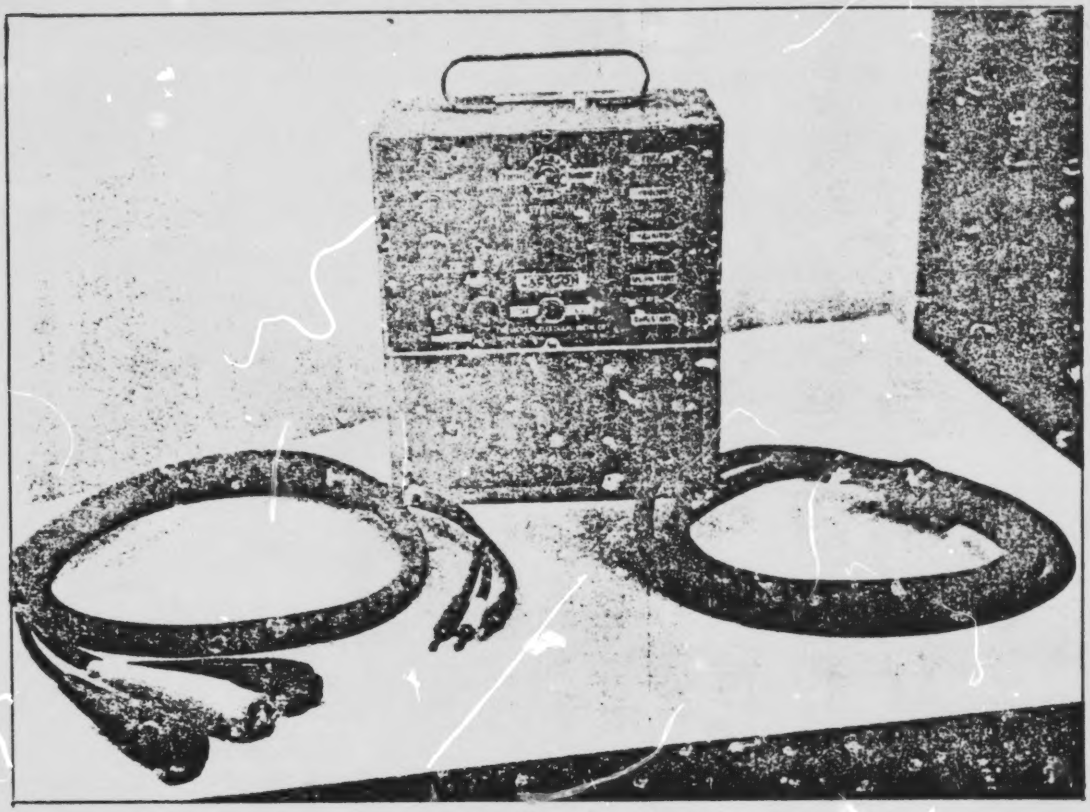

Figure 56. Motor Start-Analyzer

They have the following components

- Plug-in cord.
- Test lamp.
- On-Off switch.
- Pushbutton start switch.
- Two 175-microfarad start capacitors.
- Two capacitor switches
- A three-conductor cord to run from the instrument to the compressor. One end of this cord has plug-in type connectors and the other end has color-coded alligator clips.
- Four plug-in jacks to attach the three-conductor cords to the instrument.
- A rocker switch to reverse the direction of rotation of the motor.

Charging Hermetic Units

Hermetically-sealed units normally use a capillary tube refrigerant control. Therefore, the refrigerant charge is critical. There are two methods normally used to charge hermetic units. These methods are called the charging station, see figure 57, and the direct method. These two methods will be discussed in more detail during classroom sessions.

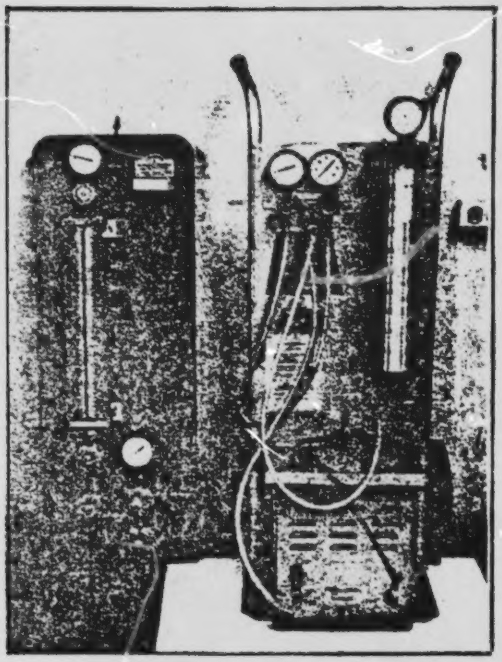

Figure 57. Charging Station

Summary

There are many different types of domestic units and an infinite number of ways of applying them. It is obvious we have not covered all these units. However, since they are basically the same we have covered some of the applications available. This has included their construction features, wiring, service and troubleshooting.

Reference:

Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.

COMMERCIAL SYSTEMS

STUDY ASSIGNMENT; Modern Refrigeration and Air Conditioning, Chapters 13 and 15

STUDY NOTES

Paragraphs 13-1 through 13-5.

These paragraphs will be perhaps a review of what you have learned previously. Each type of commercial system, depending upon its specific use, requires different designs. The paragraphs listed here and the ones that will follow discuss some of these various designs.

Paragraphs 13-6 through 13-24.

Study these paragraphs carefully. They point out the major differences between domestic and commercial refrigeration systems. The commercial system may be much larger and more complex than the domestic unit.

Paragraphs 13-25 through 32.

If you do not understand defrost systems, you will be puzzled by the extra lines, controls, and valves you will find on some systems. These systems are used only where evaporator temperatures are maintained at 32 degrees F and below, all the time.

Paragraphs 13-33 through 13-41.

Automatic controls are the brains of the refrigerating system. Service personnel usually have more trouble understanding and adjusting control than any other part of the system.

Paragraphs 13-42 through 13-49.

One of the big differences between domestic and commercial refrigeration is the use of multiple evaporators connected to one condensing unit. Different valves and controls make this possible. Like other automatic controls, these can be either pressure or temperature operated.

Paragraphs 13-50 through 13-64.

These paragraphs discuss some of the applications of accessories discussed under refrigeration components in an earlier lesson. Careful study of these accessories and their use and adjustment will make future service work considerably easier.

Paragraphs 15-1 and 15-2.

Commercial refrigeration systems produce a variety of temperatures from -60 to +60 degrees F. The refrigeration code is designed to provide standards that insure proper operation and safety. Even though you may be allowed to put in noncode installations, it is recommended you follow the code as closely as possible.

Paragraph 15-3.

Most of the information in this section is basic. It will, however, give you some excellent pointers for doing a job. Always do your work so you can answer "YES" to each of the following questions.

1. Is the system leakproof?
2. Is the system safe from outside damage?
3. Is the unit secured properly so it cannot hurt anyone?
4. Do the various parts--condensing unit, evaporator, refrigerant controls, refrigerant lines, and electrical controls have enough capacity?
5. Does the installation have the appearance of neat workmanship?

Paragraphs 15-4 through 15-8.

The importance of making a proper electrical installation cannot be overemphasized. The majority of service problems encountered have proven to be electrical in nature. One thought must always be foremost in your mind - is the system chemically clean inside? You should always see that a drier and sight glass are installed in each installation.

Paragraphs 15-9 through 15-16.

The first operation on any unit is to install the service manifold and gauges Any carelessness when installing or removing the manifold and its fittings do irreparable damage to the unit by letting moisture, air, and dirt into the machine. Use of the proper tools and fittings is a must. Keeping a system clean and removing all the air and moisture after an installation are the most important actions of the installation.

You should always test thoroughly for leaks and the leak testing equipment must be in first-class condition.

Paragraphs 15-17 through 15-19.

Another very important service operation is that of charging the system with refrigerant and transferring the refrigerant. Do not waste refrigerant, keep it clean and always be safety conscious.

The amount of refrigerant in a system is very important. Under- and overcharging will present many serious problems. Study the instructions, be sure you know how to check for the amount of refrigerant in a system and the proper methods of charging refrigerants.

Paragraphs 15-20 through 15-22.

A system should be started carefully. Avoid overloading the unit by using the service valves to keep the low side pressure at the normal level until the unit is near normal operation.

Paragraphs 15-34 through 15-39.

You assume considerable responsibility when you service a commercial installation. You are going to be responsible for thousands of dollars worth or equipment and food. Whenever you do any repair work, do it carefully. NEVER eliminate the safety devices, abuse them, or put them out of adjustment.

The condensing unit is the most expensive part of a system. Experienced service specialists find the following checklist helpful when troubleshooting.

1. Install gauges.
2. Check the refrigerant charge.
3. Check the oil level.
4. Check the condensing medium, air, or water flow.
5. Check the temperature of the components, evaporator, condenser, refrigerant lines, motors, and compressor heads.
6. Check for leaks thoroughly.
7. Aftercheck the service valves for leaks after you remove your gauges.

Paragraph 15-40.

Your biggest problem will be your ability to diagnose or locate trouble. As you study this section, figure out a logical sequence on how to locate trouble when certain symptoms are evident.

Keep in mind heat flow needs clean transfer surfaces. For example a water-cooled condenser must have both clean water passages and clean refrigerant passages.

Paragraphs 15-41 through 51.

Repairing compressors and other parts of the refrigeration system is accomplished at most Air Force refrigeration shops. This interesting function of your specialty is covered thoroughly in the paragraphs listed.

Paragraphs 15-89 and 15-90.

Authorities agree that moisture in a refrigeration system does all kinds of damage, be sure that you dry a system thoroughly. If a hermetic system seems to keep gathering moisture, it is possible the motor windings or oil is decomposing. Improper purging is a major source of moisture.

Paragraph 15-91.

A motor-compressor burnout will happen. Every serviceman must know what to do should this occur. Repeat burnouts are a definite indication of poor service.

Paragraph 15-93.

The correct amount of oil in a system is as important as the correct amount of refrigerant. Either too much or too little oil can result in damage. Always check it carefully.

Paragraphs 15-94 through 15-98.

Probably the most important thing about the suction line is it must have a minimum pressure drop and it must allow for proper oil drainage. Before you diagnose a system as being caused by a faulty motor be sure you check the belts, and that the pulleys and flywheel are in alignment and the shafts are parallel.

Paragraphs 15-99 through 15-102.

Hermetic motors must be checked and doublechecked before you decide they need service. The service chart should be gone over carefully. It's very embarassing to change a good compressor.

Paragraph 15-103.

Motor controls are seldom a source of trouble. The most frequent problem is tampering and "tinkeritis." Be sure you know the operating principles before you adjust them or you can let yourself in for a lot of trouble.

COMMERCIAL REFRIGERATION SYSTEMS

The commercial refrigeration systems are those used in businesses. These systems normally use a high starting torque compressor and an expansion valve, but some of the smaller units may use a capillary tube. Commercial units usually include: walk-in boxes, reach-in boxes, display cases, ice cream cabinets, beverage coolers, ice makers, and cold storage boxes. We will discuss only a few of the common units you will come in contact with on a day-by-day basis on an Air Force installation.

Walk-In Boxes

Walk-in boxes are designed for short to medium storage, and the length of storage time will vary from a few hours to approximately two weeks. Walk-in boxes are commonly found in dining halls, clubs, food stores, commissaries and medical facilities.

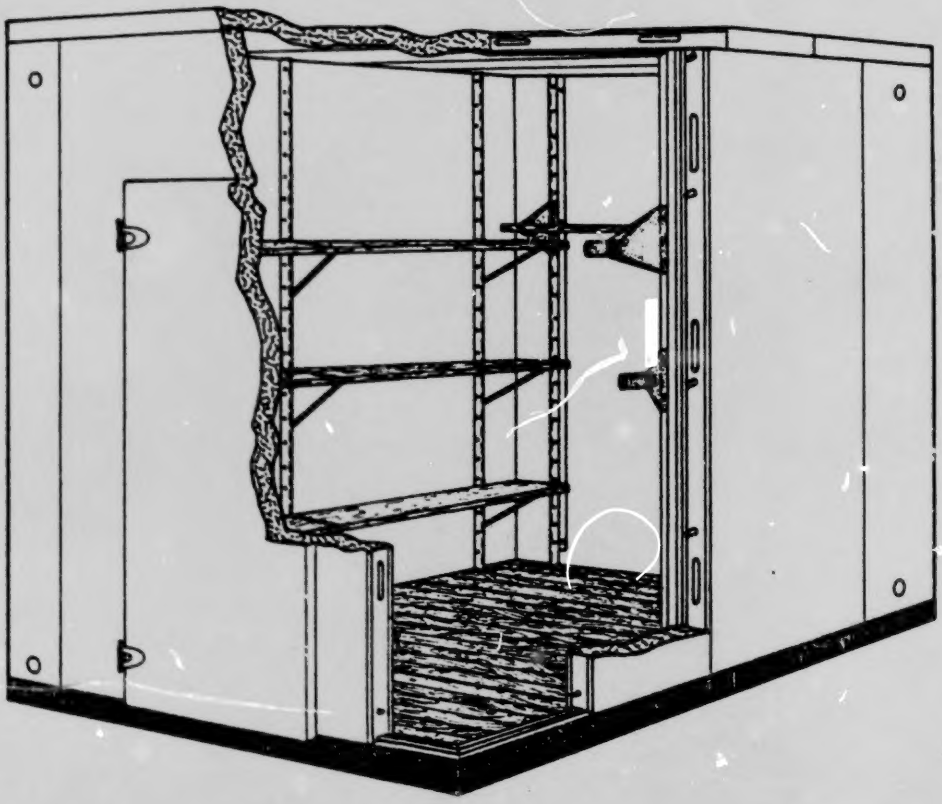

Figure 58. Sectionalized Walk-In Box

There are two types of walk-in boxes: the built-in type and the sectionalized. The built-in type is an integral part of the building and cannot be removed. The sectionalized type is built in sections and is designed to be assembled and utilized in one area either inside a building or outside of a building. If necessary it can be moved as a whole unit or disassembled and moved. These sections, see figure 58, are usually light enough to be handled by two men and are small enough to pass through a normal sized door.

INSULATION. Any substance that will retard the flow of heat may be used for insulating purposes. There is no perfect insulation. If the temperature difference is high enough and the transfer time long enough, some heat will pass through material of any thickness. Insulation is utilized for one or more of the following reasons:

- Retard heat flow.
- Prevent water condensation of cold pipes, ducts, and surfaces.
- Reduce temperature fluctuation within the refrigerated space.
- Add structural strength to the walls, ceiling, and ducts.
- Stop water vapor transmission.
- Reflect heat and light.
- Provide soundproofing.
- Provide a fire barrier.

CHARACTERISTICS OF INSULATING MATERIAL. A good insulating material should possess as many of the following characteristics as possible:

Low Thermal Conductivity (K Factor). The K Factor is the amount of heat that will pass through one square foot of insulation one-inch thick, in one hour with a temperature difference of 1°F. It becomes obvious that the better the K Factor is, the better the insulation is.

Resistance to Settling. Some materials will settle so that after a few years, the top four or five inches of the wall will not be insulated. Therefore, loose type materials should not be used in vertical walls.

Moisture Resistance. As the moisture content of an insulating material increases, its heat retarding capacity decreases. Moisture even causes some materials to swell and get larger. This could cause enough pressure to warp and damage walls. In subfreezing applications, the moisture in the insulation will freeze so that the expansion of the ice crystals will damage the walls.

Low Specific Weight. If the insulation is not strong enough to support itself, a heavy wall must be provided to support it. Furthermore, the weight of the insulation must be figured to determine the required strength and support of the ceiling.

Vermin Resistance. Rats, mice, termites, and other forms of vermin render some insulation materials worthless in a very short time.

Fire Resistance. Materials used as insulation should be noncombustible.

MAJOR TYPES OF INSULATING MATERIALS. Construction materials, such as wood, brick and concrete blocks, are not considered insulation materials. However, many walk-in boxes are constructed of wood. Therefore, both the inside and outside wall must be considered when figuring heat transfer rate.

Rockwool. Rockwool comes in either batts or bags. Batts are usually made by enclosing a layer of rockwool (1 to 4 inches) within an asphalt impregnated kraft paper envelope. This batt is then stapled between the studs in the wall. Normally, rockwool is used for air-conditioning applications only.

Fiberglass. Fiberglass is used in air conditioning as well as all types of refrigeration equipment. A low density fiberglass is used in air-conditioning applications only.

Plastic Foam. This is the lightest and best insulation material in use today. It is made in various densities for a variety of applications. Its K factor is usually about .11 to .15. It is more expensive than fiberglass. Since it has a lower K factor, less is needed to do a comparable job. Plastic foam is available in board form or it may be poured and foamed in place.

VAPOR BARRIER. Materials used to impede vapor transmission into insulation include plastics, aluminum foil, tar, asphalt, moistureproof paints, and asphalt paper.

REFLECTIVE INSULATION. Heat can be reflected in the same way as light to provide what may be called a reflective barrier. By placing a bright surface between the structural wall and the insulation, a lot of heat that would normally enter the room is stopped and reflected out. Normally, aluminum foil is used as a good reflective insulation.

Evaporators

NATURAL CONVECTION EVAPORATOR. The natural convection evaporator has no fan. The air is circulated throughout the box by the air currents inside the box. This evaporator is also known as a plate evaporator. The plate type is made by fusing two plates of metal together and forming an evaporator. The part of the evaporator coil contacting the air requires more surface area than a fin-type evaporator.

FIN-TYPE EVAPORATORS. Finned-type evaporators use fans as the means of circulating air. The evaporator may be mounted in the corner of the box, to occupy the least amount of space, and as far as possible from the door. The coil and fan are enclosed in a metal case, which is designed for ease when servicing components. An evaporator that is mounted on the center back wall is not normally very wide or deep. It is mounted near the top of the box and the air comes out the sides and returns through the front of the evaporator.

CEILING MOUNTED EVAPORATORS. This evaporator is normally thin and small with the coil covering the outer face of the evaporator, and the fan is mounted behind the coil. It is suspended from the ceiling to take up the least amount of space in the box. The main airflow is directed toward the door opening to cause the least amount of heat from entering the box when the door is opened.

CONDENSING UNITS. Some walk-ins use a plug type, self-contained refrigeration system that includes the evaporator, compressor, condenser, and all the accessories and electrical components. These units are bolted in place through a hole in the side of the box with the evaporator inside and the condensing unit outside. Most walk-in boxes use a remote condensing unit. These units may be hermetic, semihermetic, or open-type compressors with either air, water, or evaporative type condensers.

ACROSS-THE-LINE MOTOR STARTER

Motors of three-quarter horsepower and above require an across-the-line motor starter to provide motor protection, control starting and stopping, and to afford remote control.

Motor circuits and protective devices (fuses, circuit breakers, etc) are sized so that their capacity is 125 percent of the normal full load amperage of a motor. Example: If a motor with a 20-ampere full load is protected with a 25-ampere fuse, this motor could run indefinitely drawing 25 amperes. Since it is designed to run at 20 amperes under full load, running at 25 amperes would eventually burn it out or the windings would be permanently damaged. To prevent this damage and avoid costly replacement of the larger motors, the across-the-line motor starter is used on three-quarter horsepower and above motors.

A motor starter consists of three or four sets of heavy contacts used for closing the circuit to the motor, thermal switches, heaters, and an electromagnet, or solenoid referred to as a holding coil. The contacts are closed when voltage is applied to the holding coil. Usually, the voltage of the holding coil is the same as that of the motor controlled by the starter; however applications where a 24-volt coil is used to control a 220-volt motor are not uncommon.

Two circuits are used in motor starters. The circuit used to energize the holding coil is referred to as the "control circuit," and contains a manually operated switch or automatic switch (thermostat), thermal switch and the holding coil. The circuit to the motor is referred to as the "load circuit," and contains the load contacts (stationary and movable contacts), heater or heaters, and the load (motor).

The heaters are special resistors, installed in the load circuit. The heat given off by these heaters is proportional to the current flow. As current flow increases, heat from the heater increases. Located adjacent to the heaters are normally closed thermal switches. The thermal switches are in the control circuit. If current to the motor increases beyond safe limits, heat from the heater causes the thermal switch to open, and the holding coil is deenergized, opening the load circuit.

The contacts of the thermal switches are usually held open by a mechanical catch spring, and must be closed (reset) manually.

In addition to the thermal switch or switches used in the control circuit, an additional switch or switches may be used to control the motor starter. For example, a manually operated single-pole, single-throw switch located in the control circuit can be used to energize, or deenergize the holding coil of a motor starter if manual control is desired, see figures 59 and 60.

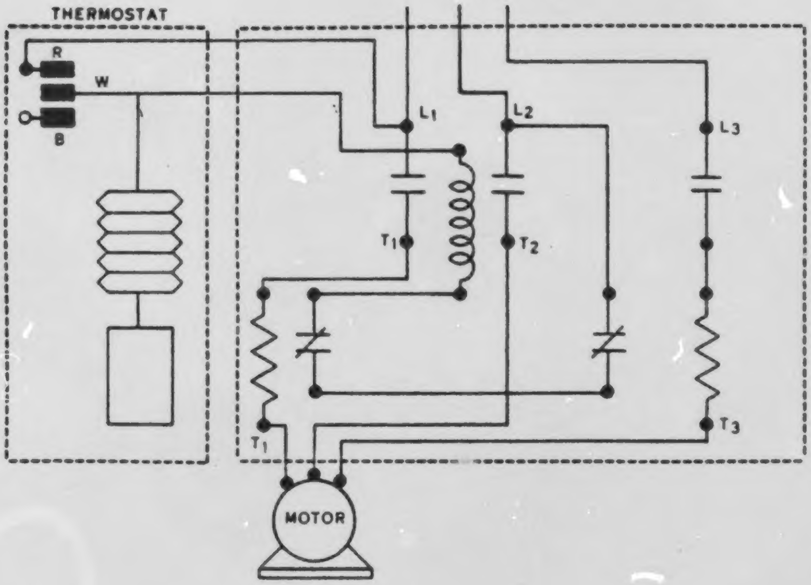

Figure 59. Three-Phase Across-The-Line Motor Starter

Many holding coils are designed for dual-voltage applications, for example, one coil may operate on 110 volts and by changing one connection the same coil can be used on 220 volts. Actually, these coils are center tapped and when 110-volt operation is desired, only half the coil is being energized.

Sizing of the motor starter is very important. Heaters that have greater current ratings than the motor being operated will not properly protect the motor. Heaters that are too small will cause nuisance tripping due to normal current flow.

To determine the proper heater for a given motor starter application you must first determine the full load amperage of the motor by checking the data plate information, then using the conversion table for the specific motor starter. Heaters from one name brand motor starter are not interchangeable with other manufacturer's products. No attempt should be made to interchange heaters.

278.

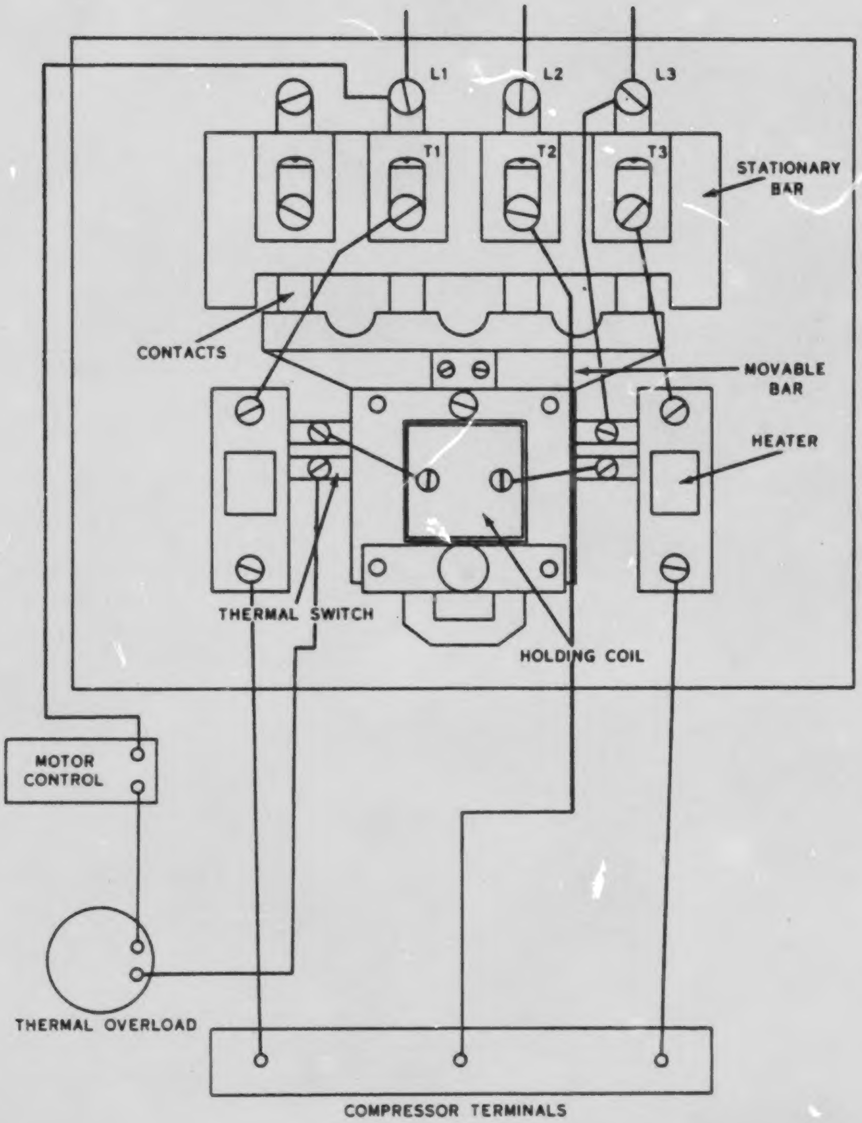
L1
L2
L3
T1
T2
T3
STATIONARY BAR
CONTACTS
MOVABLE BAR
HEATER
THERMAL SWITCH
HOLDING COIL
MOTOR CONTROL
THERMAL OVERLOAD
COMPRESSOR TERMINALS

Figure 60. Three-Phase Motor Starter

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Selecting Heaters

The overload relay size is determined by the full load current of the motor it protects. When selecting the heaters to protect a motor, you should check the motor data plate to find the full load current. Each manufacturer normally puts a heater selection table in the controller cover. Heaters are not identified by amperage, but by the manufacturer's catalog number. By using the full load current of the motor to be protected and referring to the manufacturer's table, the proper heater can be selected. Figure 61 is a Cutler-Hammer heater table. If the full load current of a 2 hp motor at 230v is 6.8 amps, the heater required would be an H1033.

HEATER COIL SELECTION TABLES

For Size 1 Starter				For Size 2 Starter		For Size 3 Starter		For Size 4 Starter	
Ampere Range	Catalog No.	Ampere Range	Catalog No.	Ampere Range	Catalog No.	Ampere Range	Catalog No.	Ampere Range	Catalog No.
.157-.177	H1101	2.20-2.45	H1024	3.89-4.35	H1028	8.72-9.67	H1035	19.5-21.9	H1042
.178-.198	H1102	2.46-2.74	H1025	4.36-4.81	H1029	9.68-10.8	H1036	22.0-24.7	H1043
.199-.223	H1103	2.75-3.07	H1026	4.82-5.35	H1030	10.9-12.0	H1037	24.8-29.0	H1044
.224-.249	H1104	3.08-3.42	H1066	5.36-5.96	H1031	12.1-13.5	H1038	29.1-31.9	H1045
.250-.280	H1105	3.43-3.81	H1027	5.97-6.63	H1032	13.6-15.0	H1039	32.0-36.1	H1046
.281-.313	H1106	3.82-4.27	H1028	6.64-7.41	H1033	15.1-16.8	H1040	36.2-40.7	H1047
.314-.353	H1107	4.28-4.71	H1029	7.42-8.23	H1034	16.9-19.1	H1041	41.8-46.2	H1048
.354-.395	H1108	4.72-5.24	H1030	8.34-9.19	H1035	19.2-21.6	H1042	46.3-52.4	H1049
.396-.445	H1109	5.25-5.87	H1031	9.20-10.2	H1036	21.7-24.5	H1043	52.5-59.2	H1050
.446-.499	H1110	5.88-6.48	H1032	10.3-11.4	H1037	24.6-27.8	H1044	59.3-66.3	H1051
.500-.562	H1111	6.49-7.27	H1033	11.5-12.8	H1038	27.9-31.5	H1045	66.4-75.1	H1052
.563-.631	H1112	7.28-8.14	H1034	12.9-14.1	H1039	31.6-35.5	H1046	75.2-87.1	H1054
.632-.711	H1113	8.15-9.03	H1035	14.2-15.9	H1040	35.6-40.3	H1047	87.2-99.9	H1055
.712-.799	H1114	9.04-10.0	H1036	16.0-18.1	H1041	40.4-45.6	H1048	100. -113.	H1056
.800-.903	H1115	10.1-11.2	H1037	18.2-20.4	H1042	45.7-51.8	H1049	114. -129.	H1057
.904-1.01	H1116	11.3-12.5	H1038	20.5-23.3	H1043	51.9-58.6	H1050	130. -135.	H1058
1.02-1.13	H1117	12.6-13.8	H1039	23.4-26.5	H1044	58.7-65.2	H1051	-------	-----
1.14-1.27	H1018	13.9-15.6	H1040	26.6-30.3	H1045	65.3-74.3	H1052	-------	-----
1.28-1.43	H1019	15.7-17.7	H1041	30.4-34.7	H1046	74.4-86.3	H1054	-------	-----
1.44-1.60	H1020	17.8-19.9	H1042	34.8-39.6	H1047	86.4-90.0	H1055	-------	-----
1.61-1.79	H1021	20.0-22.5	H1043	39.7-45.0	H1048	---------	-----	-------	-----
1.80-1.98	H1022	22.6-25.3	H1044	---------	-----	---------	-----	-------	-----
1.99-2.19	H1023	25.4-27.0	H1045	---------	-----	---------	-----	-------	-----

Figure 61. Cutler-Hammer Heater Table

MOTOR CONTROLS

Pressure Controls

Pressure-type motor controls are used on units because of the following advantages. The control can be placed on or near the condensing units removing the necessity of long electrical leads. The feeler element of a pressure motor control senses the average pressure of the box. The feeler bulb of a thermostatic motor control senses the temperature of a small area only. Pressure controls can be adjusted to guarantee a complete defrosting of the evaporator during each cycle. The main disadvantage of pressure-type controls is that they cannot be used if the condensing unit operates in a low ambient temperature. If the ambient temperature drops too low the low side pressure will not increase enough to turn the unit on.

Thermostatic Motor Control

The thermostatic motor control turns the unit on regardless of the low- or high-side pressures. There are two major advantages of thermostatic motor controls. It will compensate for slightly oversized or undersized evaporators and maintain close control of box temperatures. The main disadvantage is that you cannot guarantee complete defrost of the evaporator during each defrost cycle.

Adjusting Motor Controls

At the present time there are several manufacturers making motor controls. Each of these controls uses the same basic principles of operation. If you understand the principles of operation and application of controls, you can adjust any control with very little difficulty. Before adjusting any control the first thing to determine is the average box temperature. The next thing to determine is the allowable range that is the difference between the cut-out and cut-in. The range should be as small as possible without causing the condensing unit to short cycle. Normally, commercial units use a range of 10 degrees. The next thing to determine is the T. D. of the evaporator. When we speak of T. D. of an evaporator, we are talking about the temperature difference between the boiling refrigerant in the evaporator and the temperature of the air entering the evaporator. After determining the average box temperature range and evaporator T. D. you make out a condition sheet.

Assume the following conditions:

Average box temperature - 40° and range of 10°

Evaporator T. D. - 10°

Step 1. Make a condition chart as illustrated below:

	Box Temp	Evap Temp	Suction Pressure
Cut-In	45°F	45°F	41.6psi
Cut-Out	35°F	25°F	25.6psi
Differential	10°F		

Step 2. Determine the cut-in and cut-out temperature. If the average box temperature is 40 degrees with a range of 10 degrees, the cut-in will be 5 degrees above 40 and the cut-out will be 5 degrees below. Therefore, the cut-in is 45 and the cut-out is 35 degrees. Place these figures in the chart.

Step 3. Subtract the cut-out from the cut-in. This figure (10°) is the temperature differential.

Step 4. Fill in the evaporator temperature block. With the compressor off and the evaporator fan running, at the cut-in the evaporator and box temperature will be the same. Place the number 45° in its proper place.

Step 5. At cut-out, the evaporator temperature will be 10° less than the box temperature. We are using a 10 degree T.D. evaporator. Place the figure 25° in its proper place.

Step 6. Use your temperature pressure relationship chart and look up the suction pressure for 45° and 25°. In this case, it is 41.6 and 25.6 psig. Place these numbers in their proper place.

Step 7. Subtract the cut-out suction pressure (24.6) from the cut-in suction pressure (41.6). This number is the pressure differential.

Safety Switches

HIGH SIDE SAFETY SWITCH. The high side safety switch is installed in the high side to protect the system against excessive head pressures, and is normally set 20 percent above normal operating pressure. The high side safety switch operates on the same principle as the low side motor control except the points open on a pressure rise.

OIL PRESSURE SAFETY SWITCH. The purpose of this control is to stop the compressor if the oil pressure from the oil pump falls below a preset point. It also stops the compressor in the event that oil pressure fails to build up to the minimum safe level within a set time after the compressor starts.

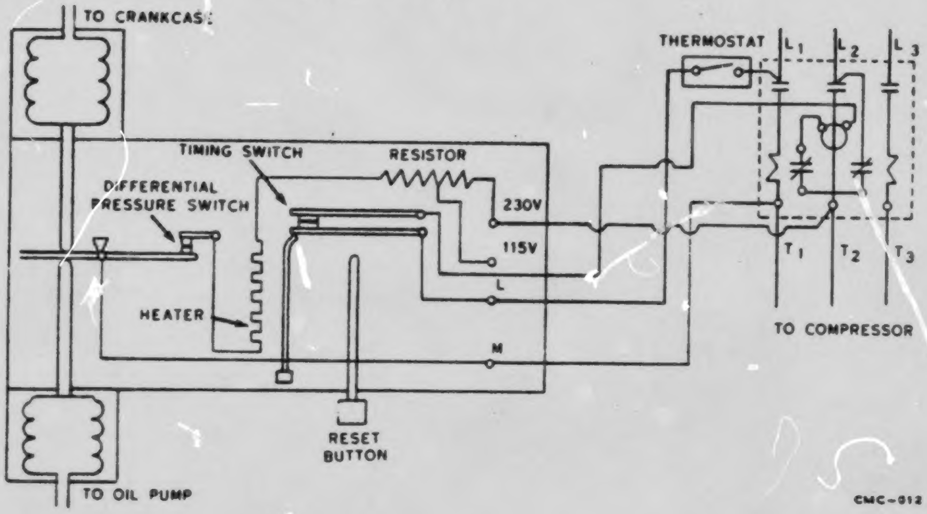

Figure 62. Oil Pressure Safety Switch

It is important to know that the total oil pressure, measured by the oil pressure gage, is the sum of the suction pressure and the oil pressure. To find the true oil pump pressure subtract the suction pressure from the oil gage pressure. The difference between the two is the pressure that is being developed by the oil pump.

Principles of Operation. The oil pressure safety switch is actuated by the true oil pressure from the oil pump. This is accomplished by using two pressure bellows opposing each other, see figure 62. One bellows is connected to the crankcase, sensing suction pressure. The other is connected to the oil pump sensing total oil pressure. The pressure difference between the two is equal to the true oil pressure. This true oil pressure actuates the pressure differential switch of the oil pressure safety switch. A time delay is wired in the safety switch which allows the compressor to operate 90 to 120 seconds with low oil pressure. However, if the pressure doesn't build up in the allowed time, the safety switch will shut the compressor off. To restart the compressor, the control must be manually reset.

Current Flow. The timing switch is wired in series with the holding coil of the line starter, and the heater is wired in parallel with the holding coil. The pressure differential switch is connected in series with, and controls the operation of the relay heater. The resistor in series with the relay heater limits the current flow to the heater and makes the control adaptable to 115-volt and 230-volt circuits. Since the oil pump operates only when the compressor operates, the total oil pressure will be the same as suction pressure when the compressor is off. Both the timing relay heater and holding coil are energized on startup. When the compressor starts and the oil pump pressure builds up to the cut-in point of the safety switch, the pressure differential switch will open and remove the heater from the circuit. The compressor will then operate normally. If the oil pump pressure doesn't build up to the cut-in pressure in the allotted time, the pressure differential switch won't open leaving the heater in the circuit. The heat from the heater will cause the bimetal strip to warp and open the timing switch. This stops current flow to the holding coil and stops the compressor. If the oil pump pressure falls below the cut-out point during operation of the compressor, the differential pressure switch will close and energize the heater. If the oil pressure doesn't build up in the allotted time (90 to 120 seconds) the operation of the heater will open the timing switch and stop the compressor, figure 62.

Setting the Oil Pressure Safety Switch. Both the cut-in and cut-out pressures should be set in accordance with the manufacturer's specifications. If they are not known, general practice is to set the cut-in approximately 5 psi below the true oil pressure. The cut-out should be set for a pressure approximately 5 psi below the cut-in pressure. For example, if the suction pressure is 38 psig and the total oil pressure is 73 psig this means the true oil pressure is 35 psi (73 - 38 = 35). The cut-in should be set at 30 and the cut-out at 25.

BASIC METHODS OF DEFROST

Before discussing the defrost systems, let's first find out why we must defrost a system. The purpose of an evaporator is to absorb heat from the surrounding area. This heat comes from the item being stored plus heat penetration through the walls, windows, doors, roof, and floor. The evaporator must be able to absorb as much heat as the refrigerant circulating through the system can carry away. If something slows this process up, the conditioned space will become warmer and spoilage of the items being cooled will occur. The evaporator is a key to good cooling. If the evaporator is kept clean, its ability to absorb heat is high. If the evaporator is allowed to get dirty the efficiency will drop and it will be difficult to maintain the desired temperature in the refrigerated space. One of the biggest factors that prevent the evaporator from absorbing heat is frost. Frost will retard heat transfer. To eliminate some of the frost problems it is important to maintain the equipment in a properly adjusted condition. In the early days, frost was removed from the evaporator by scraping the evaporator with some blunt object such as wooden paddles. Now in most boxes, frost is removed automatically by defrost systems. We will discuss some of the methods used today to accomplish the job of defrost.

Pressure Control Defrost

In the early twenties, manufacturers came out with finned-type evaporators. It was essential that they be defrosted frequently to keep the coils as free from frost as possible to maintain a constant temperature. The pressure control defrost method is common on finned gravity or blower type evaporators in walk-in boxes and display cases. This is primarily used on equipment which maintains a temperature above 32°. The control will not allow the unit to come back on until box temperature has warmed sufficiently to defrost the evaporator on the off cycle. It works like a low pressure switch. Each time the box temperature is satisfied, the switch opens and will not close until the evaporator has reached 35°.

Temperature Control

The temperature defrost control operates in much the same manner as the pressure defrost control except that it senses temperature instead of pressure. The sensing bulb is located in a convenient place on the evaporator. It is located so that the whole evaporator will be defrosted each time the compressor cycles off.

Two-Temperature Defrost

This defrost system employs two remote bulbs instead of one. One of the bulbs is attached to the evaporator, and the other is exposed to the refrigerated air. The switch mechanism is so designed that the bulb attached to the evaporator can only close the switch and start the compressor, and the bulb which is exposed to the air can only stop the compressor. In this way the bulb on the evaporator assures a complete defrost each time the compressor stops. This control is limited to use on boxes with a temperature above 32°. It has its limitations, one being that if the load becomes very heavy there may be difficulty in obtaining a complete defrost.

Pressure-Temperature Defrost

The defrost is controlled by the pressure on the refrigerant, and the air temperature is controlled by the thermostat. This type of system will give a better defrost each time. It is very effective on boxes with a temperature above 35°. This defrost cycle cannot be used effectively on evaporators for ice making, storing of frozen foods, or evaporators below 35°. On the particular application where it is used, it has a better control of the box temperature and does not allow the box to warm up more than a few degrees.

Time Shutdown Defrost

This defrost system is used on boxes that have a range from 25 to 35°. The compressor can be shut down several times in a 24-hour period if required. The shutdown time should be selected when the load is the lightest or when the usage of the box is light, such as during closing hours or at night. With this system the compressor can be shut down for as long as 4 to 5 hours at a time to assure a complete defrost of the evaporator. Each installation varies so the stopping and starting time will vary. This will be done on a trial basis until you are satisfied and complete defrosting is accomplished.

Time-Pressure Defrost

This method is a combination of the pressure defrost and the time defrost. The operation of the control is simple. The timer stops the unit, and the low-pressure control is set for approximately 38 to 40 psig or about 41 to 43°. This defrost switch does not defrost each time the unit cycles, so a warmer box is required to completely defrost the evaporator. One of the advantages with this type of defrost is that the length of defrost is automatically adjusted.

Hot Gas-Timed Mechanical Valve

This is a combination valve and mechanical timer. One of the features of this defrost is that the hot gas line is soldered to the drain pan to heat the pan and allow the water to drain to the outside. A check valve may be necessary just ahead of the condenser to prevent obstructing the flow of hot gas to the evaporator. The fans must be stopped while the defrosting is going on especially with temperatures below 25°. When temperatures are 0 degrees or below, it is a good practice to have louvers to enclose the air handler so less heat enters the conditioned space. It aids in a more rapid defrost due to the fact that the air handler is also enclosed at this time. When this method is used, after defrosting the evaporator the condensing unit will come on but the evaporator fans will not come on until the refrigerant has reached a predetermined temperature. This action is controlled by a thermostat, and will eliminate hot air from being blown into the conditioned space. One disadvantage of hot gas defrosting is a lack of adequate heat within this gas to do a complete defrost on the evaporator.

Major Components

In general, all defrost systems have the following components:

DEFROST TIMER. This is an electrical clock that energizes the defrost system. There are two different methods of operating the clock timer, the first is clock timing. This is the simplest and most common method used. An electric clock is wired to the plug-in cord. Any time the unit is plugged in, the clock is running. Some of the timers are set to defrost once every 12 hours, while others defrost every 6 to 8 hours. The second is running time. The electrical clock is connected to the compressor circuit. Therefore, the clock runs only when the compressor is operating. After a given number of hours of operation usually 4 to 8 hours, the timer energizes the defrost system.

DRAIN TROUGH. This unit is located below the evaporator to catch the defrost water as it drips off the evaporator.

DRAIN TROUGH HEATER. An electrical heater located below the drain trough to keep the water from freezing before it has a chance to flow out the drain line.

DRAIN LINE. A piece of copper, rubber, or plastic tubing which runs from the drain trough to remove condensate.

HEATING MECHANISM. For satisfactory operation, particularly in the freezing section, the time it takes to defrost the evaporator must be held to a minimum. This is accomplished by rapidly heating the evaporator with the hot condenser gas or an electrical heating coil.

DEFROST THERMOSTAT. This unit has several different names: defrost thermostat, termination thermostat, or safety control. Regardless of what these units are called, they all work the same and have the same function. The unit is a small circular plastic or bakelite disc with two wires attached. It is located on and attached to the evaporator. The internal mechanism consists of a bimetal element with contacts which open at 37 to 40°F and close at 18 to 24°F. It has two purposes: to keep the defrost heater from getting hot unless the evaporator is cold, and to stop or terminate the defrost cycle when the evaporator reaches 37 to 40°F.

Hot Gas Defrost System

Figure 63 illustrates a typical hot gas defrost system. The defrost timer opens the solenoid valve and allows the hot condenser gas to flow through the bypass line into the evaporator. The hot gas gives up its heat and melts the frost on the evaporator. Defrost water collected in the drain trough flows down the drain line to the drain pan. Heat from the condenser evaporates the water. The drain trough heater keeps the water from freezing before it flows out the drain line. Some of the hot gas condenses in the evaporator. To eliminate a liquid lock in the compressor, this liquid refrigerant is vaporized by an electrical heating element in the suction line.

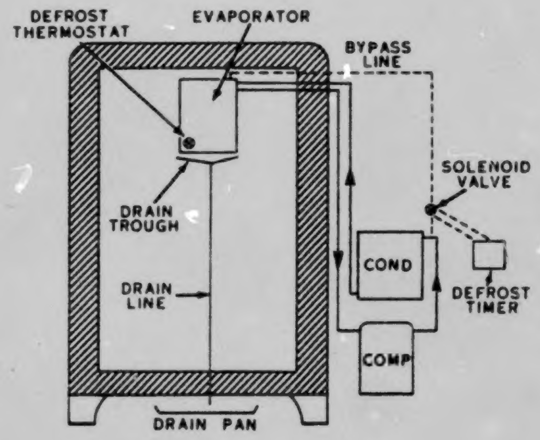

Figure 63. Defrost System

ADVANTAGES. (1) Cheap operation - by using the heat in the hot gas, the requirement for electrical power is reduced, (2) Fast operation - the hot gas is in direct contact with the tubes in the evaporator. Therefore, the ice is melted rapidly.

DISADVANTAGES. The hot gas defrost system is more difficult to troubleshoot than the electrical. If the box is located in a low-temperature area, there will not be enough heat in the hot gas to completely defrost the evaporator. The ice will continue to build up on the evaporator until it must be defrosted by hand.

Electrical Defrost System

The electrical defrost system is very simple. It consists of an electrical heating element wound around and attached to the evaporator. The defrost timer turns the compressor off and turns the defrost system on. The heating element melts the ice on the evaporator. As soon as the evaporator reaches 37 to 40°F, the defrost thermostat turns the defrost system off. After an additional 4 to 5 minutes, the defrost timer places the system back in normal operation.

Defrost System Wiring Diagram

There are several different types of defrost timers used in refrigeration. Two common types are illustrated in figures 64 and 65. Each of these timers consists of four major components: (1) Electric motor that runs continuously, (2) a rotor with lobe that makes one rotation each defrost cycle, (3) two sets of contact points, one set of points is always open when the other set is closed, and (4) four or more electrical terminals.

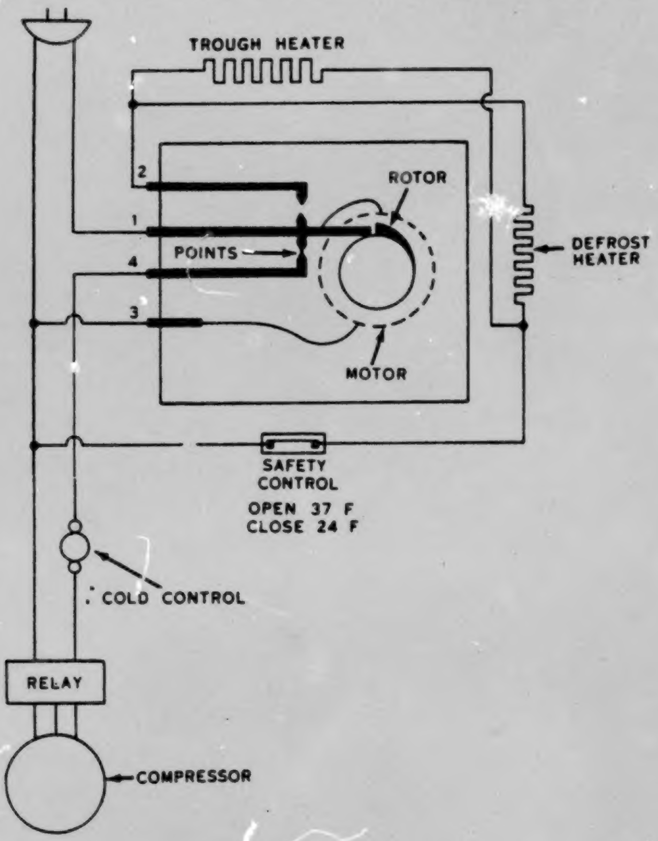

Figure 64. Wiring Diagram (New-Type Defrost Timer)

During normal operation, as shown by figures 64 and 65, electrical current is supplied to the compressor through the closed contact points. When the rotor moves far enough, terminal 1 moves up on the lobe and opens one set of contact points and closes the other. If the evaporator is cold (below 24°F for the old type), the defrost thermostat opens and stops the defrost cycle. It usually takes about 10 to 11 minutes to completely defrost the evaporator. Terminal 1 will continue to ride the lobe of the rotor for another 4 to 5 minutes. This additional time provides time for defrost water to drain out, the evaporator to cool down and the pressure in the system to equalize. As soon as the rotor moves far enough, terminal 1 drops off the lobe and places the system back in normal operation.

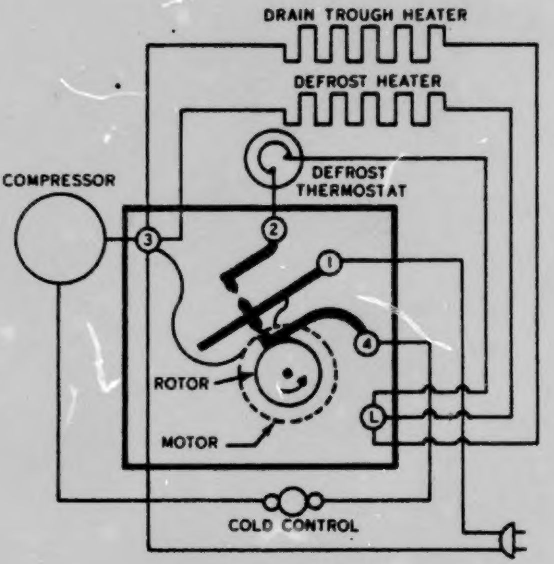

Figure 65. Wiring Diagram (Old Type Defrost Timer)

The wiring diagrams in figures 64 and 65 are for electrical defrost systems. This same timer can also be used with hot gas defrost system by substituting a solenoid valve for the defrost heater.

MULTIPLE EVAPORATOR SYSTEMS

A multiple evaporator system is one in which two or more evaporators operate at different temperatures and are connected to the same condensing unit.

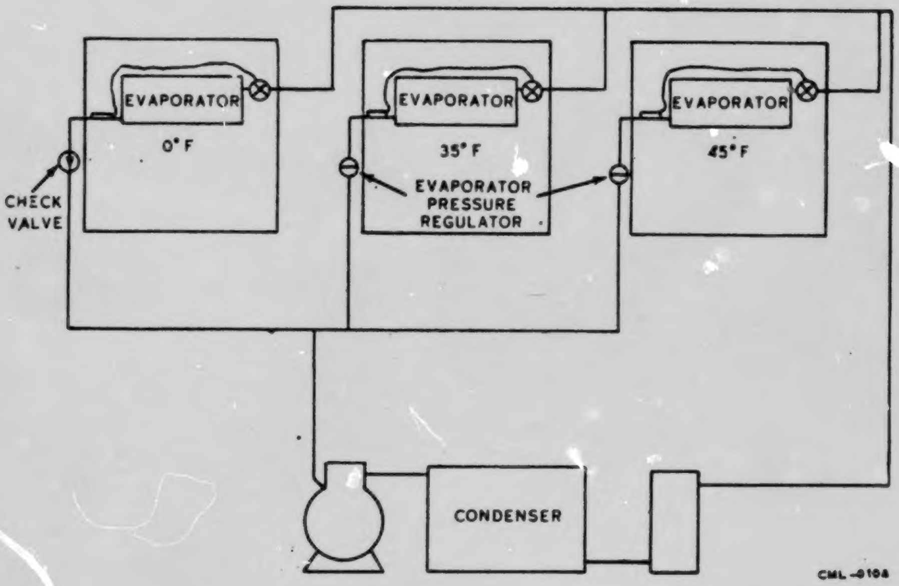

Figure 66. Evaporator Pressure Regulator System

A typical three-evaporator multiple evaporator system is shown in figure 66. An EPR (evaporator pressure regulator) valve is installed in the suction line of each of the warmer evaporators in order to maintain the pressure. This also maintains the saturation temperature (boiling point) of the refrigerant at the desired level. A check valve is installed in the suction line of the low temperature evaporator to prevent the high (pressure) from the warmer evaporators from backing up into the cold evaporator. The check valve will remain closed as long as the pressure in the main suction line is above the pressure in the low temperature evaporator. For this reason the low temperature evaporator will receive little or no cooling until the demands of the high temperature evaporators are satisfied. To rectify this, the load on the low temperature evaporator must be at least 60 percent of the total heat load. If the load is less, the compressor will operate too long at suction pressures too high for adequate refrigeration in the low temperature evaporator.

In multiple evaporator systems, the compressor is normally cycled by a low-pressure control. The control cutout pressure is set to satisfy the temperature in the coldest evaporator. When the compressor is in the OFF cycle, any one of the evaporators is able to start the compresor. If the EPR valve opens one of the high-temperature evaporators to the suction line, the pressure will rise causing the control to start the compressor.

Solenoid Valve System

Thermostatically controlled solenoid valves in the liquid or suction lines of the high-temperature evaporators are also used in multiple evaporator systems. A typical system of this type is shown in figure 67.

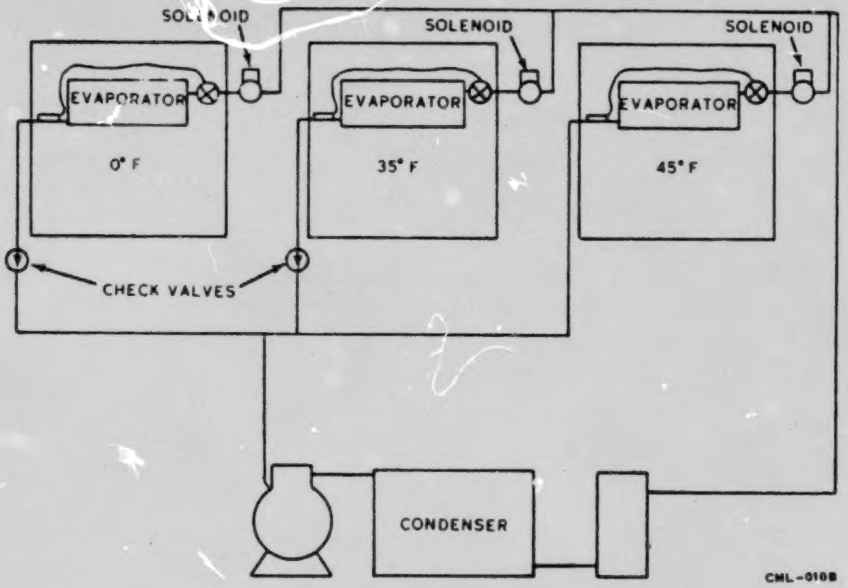
SOLENOID
SOLENOID
SOLENOID
EVAPORATOR
EVAPORATOR
EVAPORATOR
0° F
35° F
45° F
CHECK VALVES
CONDENSER
CML-0108

Figure 67. Solenoid Valve System

The operation of this system is similar to the EPR type system except that there is no control of evaporator pressure and temperature. A thermostat in the refrigerated space of each box controls the solenoid valves. When the thermostat for a particular space is satisfied, it will allow the solenoid valve to close, shutting off refrigerant flow to that evaporator. If all the solenoids have closed the system will pump down and shut off the low pressure control.

Check valves should be installed in the suction lines of the colder evaporators to prevent pressure from the warmer evaporator from backing into the colder evaporators.

MULTIPLE COMPRESSOR SYSTEMS

A multiple compressor system is one with two or more compressors operating to cool one refrigerated space. The compressors may be hooked in parallel or in series depending on the type of application. A typical multiple compressor system with the compressors connected in parallel is shown in figure 68.

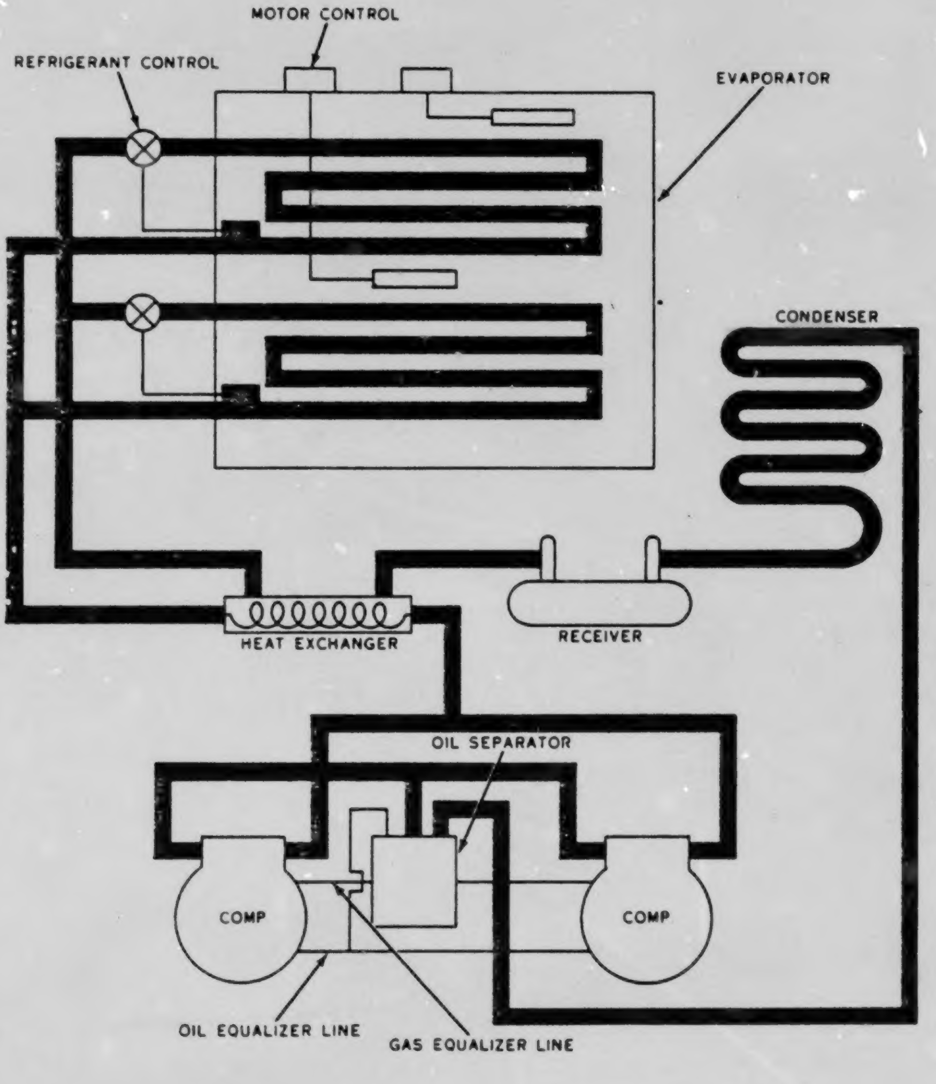
MOTOR CONTROL
REFRIGERANT CONTROL
EVAPORATOR
CONDENSER
HEAT EXCHANGER
RECEIVER
OIL SEPARATOR
COMP
COMP
OIL EQUALIZER LINE
GAS EQUALIZER LINE

Figure 68. Multiple Compressor System

Direct Staged System

In this system the compressors are connected in series. One compressor will compress the refrigerant and discharge it into the suction of the other. The pressure of the refrigerant is increased by the second compressor and discharged into the condenser. The same refrigerant is used throughout the system.

Cascade System

This system is composed of two complete refrigeration units connected by an interstage heat exchanger. This heat exchanger is the condenser for one unit and the evaporator for the other. The evaporator of the high-pressure unit removes heat from the condenser of the unit that reaches ultra-low temperatures. Two different refrigerants must be used in this system.

Equalizer Lines

There will be a small difference in crankcase pressures. This difference is corrected by using equalizer lines. The suction pressure must be the same at both compressors. The oil collects in the compressor with the lowest crankcase pressure. This will cause the other compressor to fail because of the lack of oil. The gas and oil equalizer lines are connected to the crankcase of both compressors. The gas equalizer line must be installed above the maximum oil level. The oil equalizer line must be installed below the minimum oil level.

TROUBLE ANALYSIS OF COMMERCIAL UNITS

Determining the cause of a malfunction in a refrigeration system is usually much more difficult than repairing it once the trouble is located. It is important that a step-by-step procedure be followed when troubleshooting a system. A hit-or-miss procedure or parts changing will result in a waste of time and may compound your trouble rather than correcting it. The refrigeration specialist should listen to the user's complaint, and often this will give a clue as to the possible trouble. Following a trouble analysis chart may be an aid to you in finding possible troubles. The mistake made by most refrigeration specialists is in forming an opinion without properly checking the equipment. This results in both wasted man-hours and equipment.

Summary

Commercial refrigeration is similar to air conditioning as far as the basic equipment is concerned, but we deal with various pieces of equipment such as timers, defrosting the coils, low temperatures to high temperatures, preservation of foods, beverages, produce and anything that will require freezing. Troubleshooting a commercial refrigeration system can be more complicated than a regular air-conditioning unit, and at low temperatures we can run into troubles such as oil return. The system is only as good as the service technician that is maintaining it. The information contained in this study guide should be an aid to you.

References:

1. Textbook; Modern Refrigeration and Air Conditioning. Althouse, Turnquist, and Bracciano.
2. Textbook; Franc Refrigeration Manual.
3. RSES Service Application Manual.
4. Textbook; Commercial and Industrial Refrigeration. Nelson.

ATC-SHEPPARD AFB TEX. 74-1881

PREPARE THE MAN WORKBOOKS 3AZR54550-2-II-1-P1 thru II-2-P4

Department of Civil Engineering Training

Refrigeration and Air Conditioning Equipment

REFRIGERATION SYSTEMS MAJOR COMPONENTS

September 1974

SHEPPARD AIR FORCE BASE

11-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

PROJECT	TITLE	PAGE
II-1-P1	Check Operation of Compressor, Condenser, Evaporator, Metering Device, and Size Refrigeration System Piping	1
II-2-P1	Wiring Electrical Relays	17
II-2-P2	Analyzing Hermetic Compressors	25
II-2-P3	Wiring Commercial Systems	33
II-2-P4	Operation and Adjustment of Multi-Evaporator Systems	45

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Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-II-1-P1
September 1974

CHECK OPERATION OF COMPRESSOR, CONDENSER, EVAPORATOR, METERING DEVICE, AND SIZE REFRIGERATION SYSTEM PIPING

OBJECTIVES

Upon completion of this project you will be able to:

Interpret temperature and pressure readings and diagnose the operating conditions as normal or abnormal.

Check the compressor, condenser, evaporator, and metering device for correct operating conditions.

Size refrigeration lines so they will have velocities and pressure drops that are within the acceptable limits of good design.

Standard of performance:

The standard of performance for this project is, 100% completion, error free

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-II-1-P1	1/student
Pen or pencil	1/student

PROCEDURE

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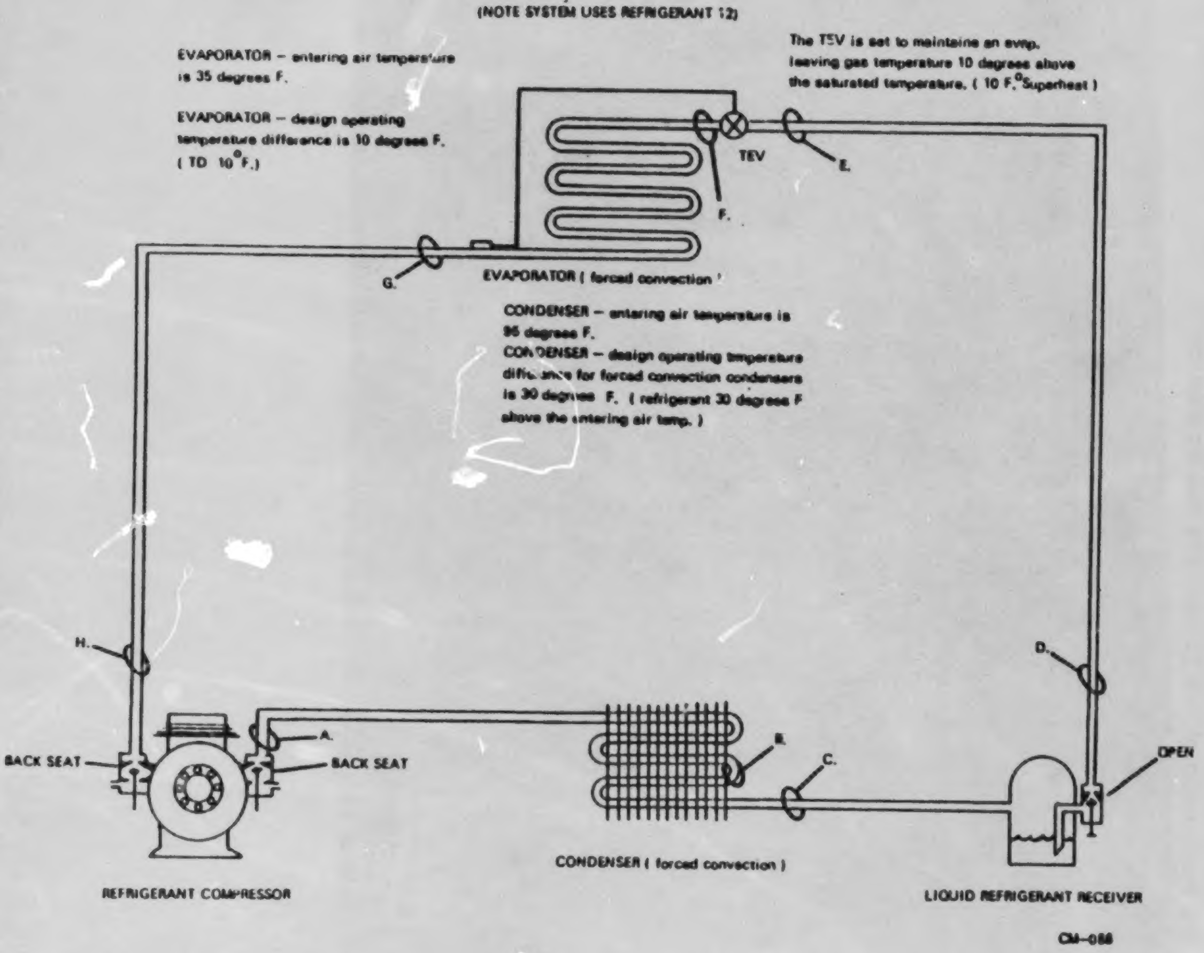


(NOTE SYSTEM USES REFRIGERANT 12)

EVAPORATOR – entering air temperature is 35 degrees F.

EVAPORATOR – design operating temperature difference is 10 degrees F. (TD 10°F.)

The TEV is set to maintaine an evap. leaving gas temperature 10 degrees above the saturated temperature. (10 F.° Superheat)

CONDENSER – entering air temperature is 95 degrees F.

CONDENSER – design operating temperature difference for forced convection condensers is 30 degrees F. (refrigerant 30 degrees F above the entering air temp.)

TEV
E.
F.
G.
EVAPORATOR (forced convection)
H.
D.
BACK SEAT
A.
BACK SEAT
B.
C.
OPEN
CONDENSER (forced convection)
REFRIGERANT COMPRESSOR
LIQUID REFRIGERANT RECEIVER
CM-088

PART 1

Operation

1. Using the above diagram of a refrigeration system, answer the following questions.

2. What refrigerant pressures should exist at the following points of the system, while operating at the entering air temperatures shown?

POINTS	PRESSURE
A.	________
B.	________
C.	________
D.	________
E.	________
F.	________
G.	________
H.	________

3. What refrigerant temperatures should exist at the following points of the system, while operating at the same entering air temps as above.

POINTS	TEMPERATURE
B.	________
F.	________
G.	________

12- 75-621

4. Would the temperatures at points C, D, and E be more or less than point B?

EXPLAIN: ____

____

____

5. Why should point A. be at a higher temperature than point B? ____________

____

____

6. Why is the temperature at point G. higher than point F? ______

7. Will point H normally be at a higher temperature than point G? ______

8. What caused a higher temperature at point H? ______

9. Do NORMAL pressures depend on the entering air conditions? EXPLAIN:

10. What caused the quick temperature reduction from point E to point F?

11. What refrigerant temps and pressures will exist at points F and G if the entering air is 30°F?

F. ______ TEMP.
F. ______ PRES.
G. ______ TEMP.
G. ______ PRES.

12. If 30°F is the desired average space temperature, what should the temperature control be set at to maintain the temperature within a 10-degree temperature range?

15 degree temp range? ______

13. What would the pressure be in the evaporator, with no suction line pressure loss, when the compressor is at the cutout point, for a 10-degree operating temperature range in the space?

____

For a 15°F temperature range ______________________________

14. Can the operation of a condenser be described as a constant temperature constant pressure process? ______________________________

15. How does heat loading of the evaporator affect the suction pressure?

____

16. How does the load affect the high side pressure? ______________________________

EXPLAIN: ______________________________

17. What should the discharge pressure of the compressor (C) be with SHOWN condenser air temps?

____

18. What controls the discharge pressure of the compressor (C)?

____

____

19. Will high superheat, entering the compressor (C) cause the compressor to discharge the refrigerant at abnormally high temperatures? EXPLAIN:

____

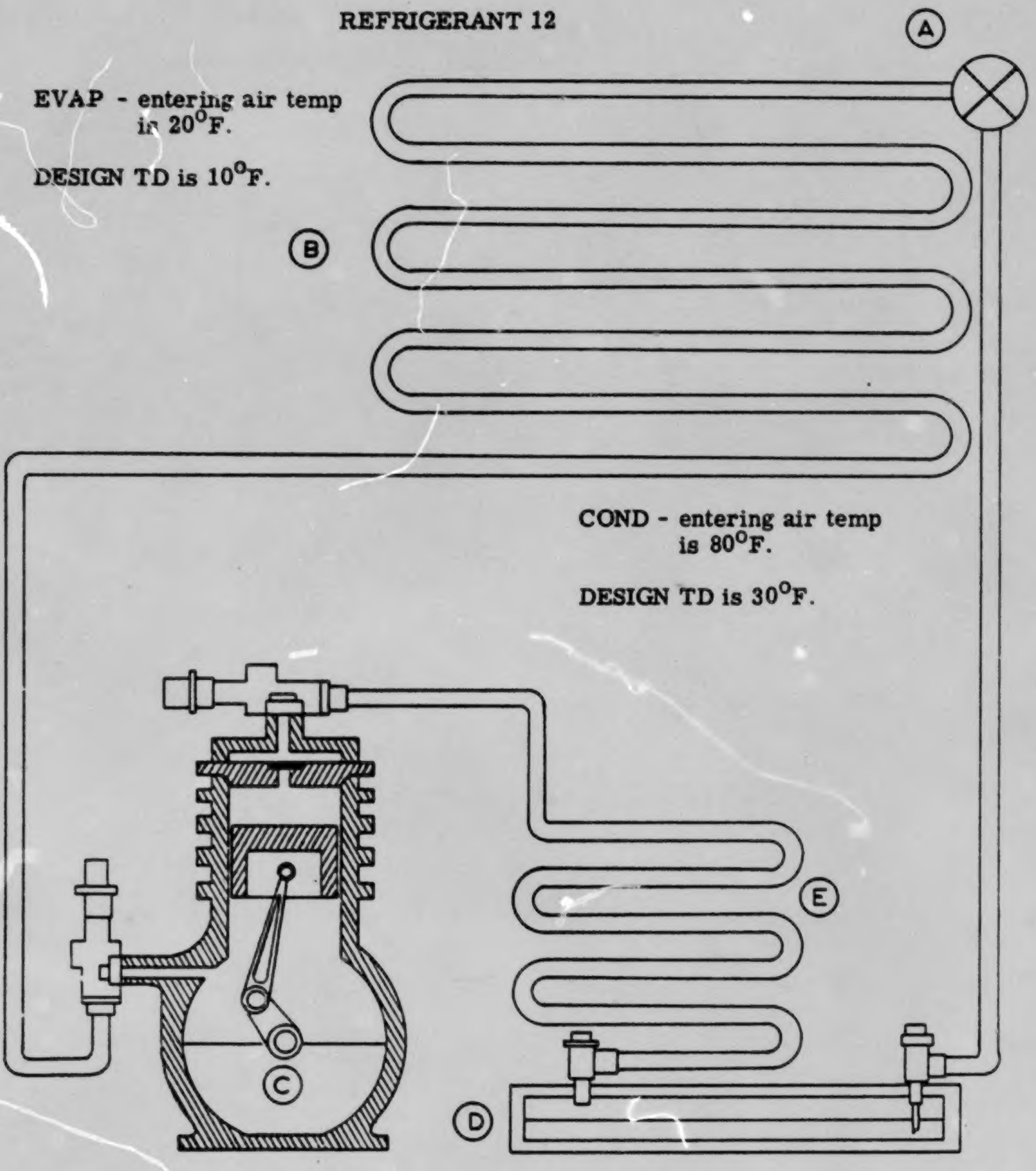
____

____

20. What characteristic of the condenser affects the compressor discharge temperature? ______________________________

____

INSTRUCTIONS: Refer to the system diagram below and then answer questions 17 through 26.


REFRIGERANT 12
A
EVAP - entering air temp is 20°F.
DESIGN TD is 10°F.
B
COND - entering air temp is 80°F.
DESIGN TD is 30°F.
E
C
D

21. Does the air temperature rise through the condenser indicate that the condenser is doing its job?

____

22. What should the condensing temperature of the refrigerant be? ______________

23. What should the condenser leaving liquid temperature be, if no subcooling takes place in the condenser? ______________

24. What should the evaporating pressure be? ______________

25. If the expansion valve (A) was an automatic (constant pressure type), what pressure would be required to maintain 15°F in the space?

____

26. Would the degree of superheat be constant? ______________

PART II

Pipe Sizing

INSTRUCTIONS: Using the piping schematic on page 9 and the piping tables in your study guide, size the lines and complete the following:

1. Liquid line

   a. Correction factor at 45° suction and 125° condensing temperature is________.

   b. Corrected tonnage is____________________.

   c. Length of the liquid line is_______________.

   d. Estimated line size is__________________.

   e. Equivalent length of valves and fittings is____________________.

   f. Total equivalent length of liquid line is______________________.

   g. The liquid line size should be____________, which will give a tonnage capacity of__________________and a line pressure drop of________________.

2. Suction Line

   a. Correction factor is________________________.

   b. Corrected tonnage is______________________.

   c. Length of the suction line is_________________.

   d. Estimated line size is_______________________.

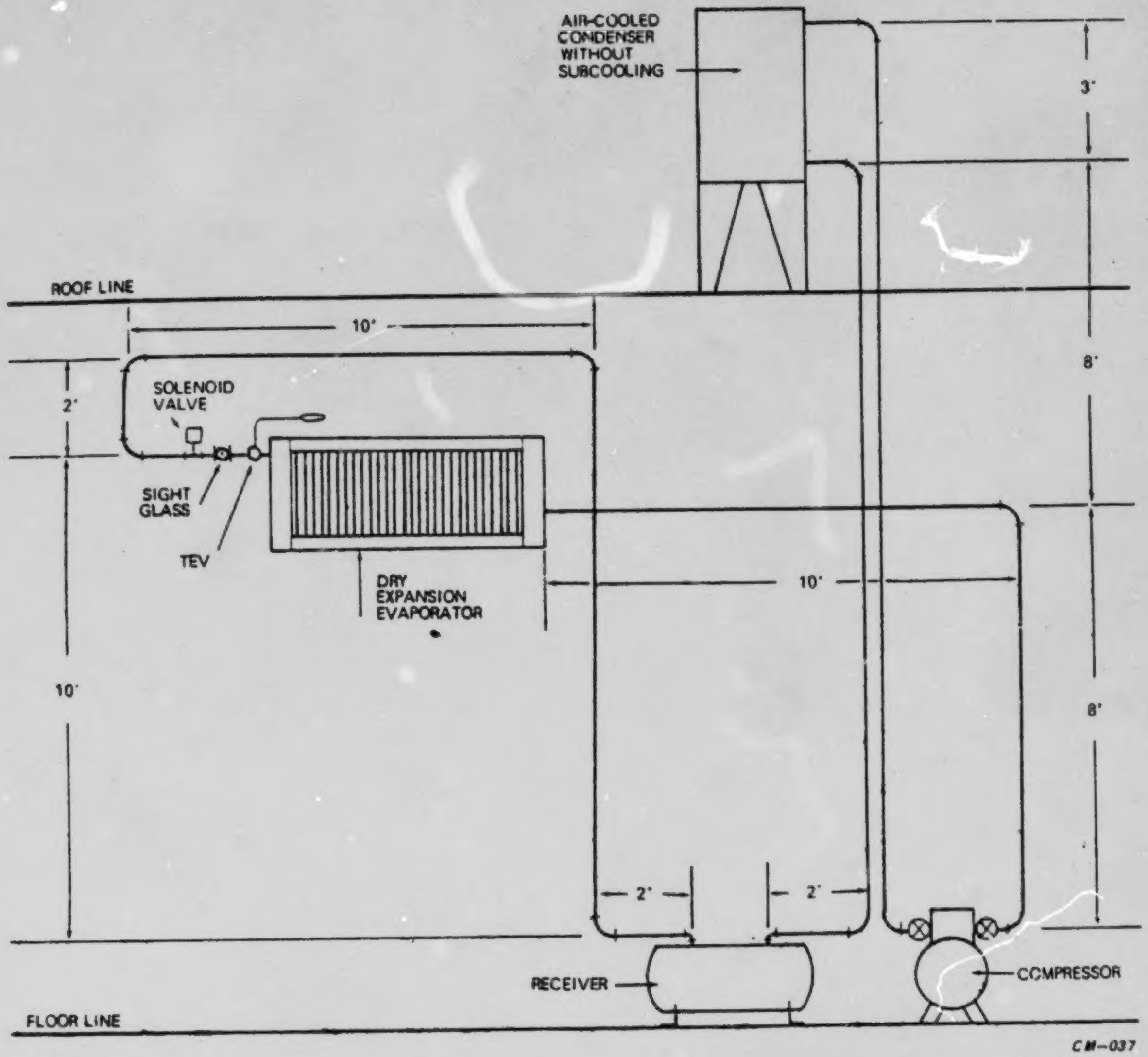
   e. Equivalent length of valves and fittings is________________, making a total equivalent length of______________________.

   f. The suction line size should be___________, which will give a tonnage capacity of___________and a line pressure drop of_____________.

   g. Suction gas velocity check:

      (1) Correction factor for velocity is___________, which gives a corrected tonnage of___________________.

      (2) Velocity at this line size and corrected tonnage is___________________.


AIR-COOLED CONDENSER WITHOUT SUBCOOLING
3'
ROOF LINE
10'
2'
SOLENOID VALVE
SIGHT GLASS
TEV
DRY EXPANSION EVAPORATOR
8'
10'
10'
8'
2'
2'
RECEIVER
COMPRESSOR
FLOOR LINE
CM-037

FULL LOAD	18 Tons
SUCTION TEMPERATURE	45°F
CONDENSING TEMPERATURE .	125°F
REFRIGERANT	R-12

VALVES:
On Receiver - Globe
On Compressor - Angle

ELBOWS - Short Radius

3. Discharge Line

   a. Correction factor is__________which gives a corrected tonnage of__________.

   b. Length of the discharge line is__________________.

   c. Estimated line size is________________________.

   d. Equivalent length of valves and fittings is__________________, which gives a total equivalent length of__________________.

   e. The discharge line size should be___________________, which will give a tonnage capacity of___________________and a line pressure drop of____________.

   f. Discharge line velocity check:

      (1) Correction factor for velocity is____________________, which gives a corrected tonnage of___________________.

      (2) Velocity at this line size and corrected tonnage is______________________.

4. Condenser drain line

   a. Correction factor is___________________which gives a corrected tonnage of ________________________.

      NOTE: To compute correction factor for condenser drain lines, use the table for liquid line correction factor.

   b. Length of condenser drain line is___________________, which gives an estimated line size of______________________.

   c. Equivalent length of valves and fittings is___________________, which gives a total equivalent length of_____________.

   d. The condenser drain line size is_________________, and the condenser should be located at least_______________inches above the receiver.

5. Have the instructor check your work.

Checked by________________________________
Instructor

COMPRESSOR CAPACITY AND CAPACITY CONTROL

Figuring Capacity

INSTRUCTIONS: Using a pencil, fill in the answers below:

1. **What conditions exist within a compressor which affects volumetric efficiency.**

2. **Using the formula $Q = \frac{D^2 \times L \times N \times rpm}{2200}$, compute the displacement of a reciprocating compressor which has a 2.5-inch bore, 3-inch stroke, 6 cylinders, and is turning at 1750 rpm.**

3. Using the answer from 2 above, compute the tonnage of the compressor assuming that each ton is capable of pumping 3.25 cfm or refrigerant vapor.

Capacity Control System

1. Identify the numbered components indicated in the unloader system diagram, located following the fill-in blanks below, by matching the component number with the components listed below.

NO.	NAME	PURPOSE
	Hydraulic Relay	
	Hydraulic Relay Piston	
	Ball and Spring Assembly	
	External Adjusting Stem	
	Push Pins	
	Control Oil Pressure Line	
	Capacity Control Valve	
	Unloader Power Element	
	Lifting Fork	
	Lifter Spring and Pins	
	Suction Valve	
	Unloader Sleeve	

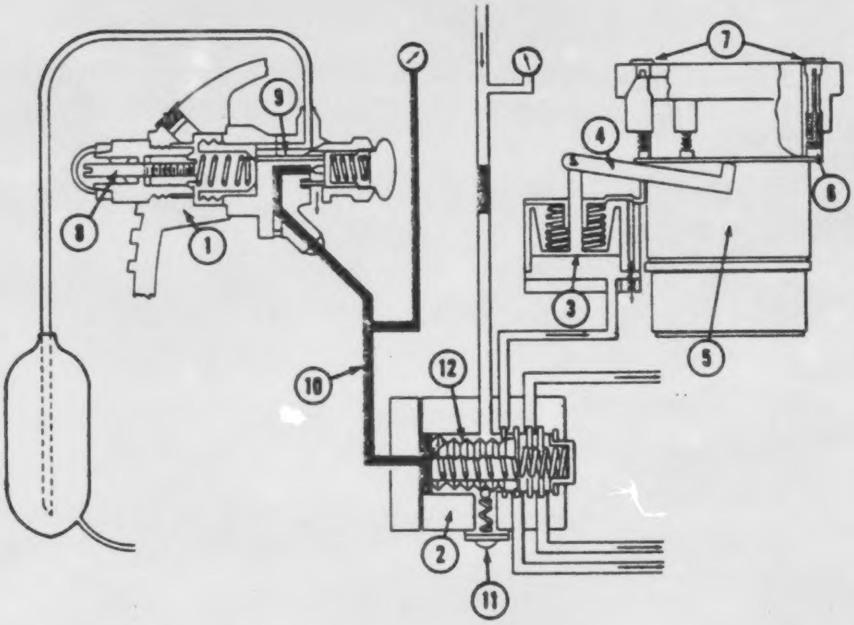
2. In the space immediately following the item's name, briefly describe its purpose.

3. In the unloader system diagram shown below, color the oil pump pressure, suction pressure, and control oil pressure according to the following color code.

    a. Oil pump pressure - Red

    b. Suction pressure - Green

    c. Control oil pressure - Black



2B-75-621

4. Operate the compressor capacity control by turning the cylinder unloader external adjusting stem counterclockwise until all the cylinders are loaded and record the following:

    a. Compressor Motor Amperes ____________________

    b. Suction Pressure ____________________

    c. Oil Pump Pressure ____________________

    d. Control Oil Pressure ____________________

    e. Evaporator Temperature ____________________

Check performance of the cylinder unloader as follows:

a. Turn the cylinder unloader adjusting stem clockwise until one cylinder unloads and record the following:

(1) Compressor Motor Amps ______________________________

(2) Suction Pressure ______________________________

NOTE. This is the control point. The last unloading step will cut out when the suction pressure drops five pounds below this point. The last loading step will cut in two pounds above this control point.

(3) Oil Pump Pressure ______________________________

(4) Control Oil Pressure ______________________________

(5) Evaporator Temperature ______________________________

b. Turn the unloader external adjusting stem clockwise until another cylinder unloads.

The compressor motor is now using how many amperes? ___ ____ ________

c. Turn adjusting stem clockwise until the compressor is completely unloaded. (Do not force stem.)

d. Explain how you may determine the number of cylinders that are loaded by observing:

(1) Oil Pressure Gages ______________________________________

____

____

____

____

____

(2) Ammeter readings

5. Field method of cylinder unloader adjustment

   a. This simple method of adjustment is accomplished in four easy steps as follows:

      (1) Place a normal operating load on the system.

      (2) Fully load the compressor by turning the adjusting stem full counterclockwise (all cylinders will be loaded).

      (3) Let unit run until the evaporator temperature decreases to the desired temperature.

      (4) Turn the adjusting stem clockwise slowly until the first cylinder unloads.

6. Manufacturer's method of cylinder unloader adjustment

   a. A variation of seven pounds in suction pressure is required to operate the unloaders from fully unloaded to fully loaded positions in compressors using R-12. In compressors using R-22, an eleven-pound variation in suction pressure is required. Seven-and eleven-pound capacity control valve springs are available and must be used in conjunction with corresponding refrigerants in order to obtain proper unloader operation. If, with a given suction pressure, the external adjusting stem is turned in until the first cylinder unloads (known as the control point) the last unloading step will cut out when the suction pressure drops five pounds below this point. The last unloading step will cut in two pounds above this control point.

      (1) Determine the saturation pressure corresponding to the minimum desired evaporator temperature. This information will be provided by the instructor.

      (2) Determine the control point by adding 5 psi for R-12 (8 psi for R-22) to the saturation pressure.

      (3) With the adjusting stem all the way out, operate the system under the full-load conditions to obtain a suction pressure higher than that of the control point.

(4) Reduce crankcase pressure to the control point by slowly front seating the suction service valve.

(5) Turn the control valve adjusting stem in slowly (clockwise) until the first cylinder unloads. (One full turn of the valve stem changes the unloading point 6 pounds.)

(6) Recheck by opening suction shutoff and then slowly closing. Observe suction pressure gage and listen for the first cylinder to unload when suction pressure reaches the control point.

(7) Open suction shutoff valve.

WIRING ELECTRICAL RELAYS

OBJECTIVES

Upon completion of this project you will be able to:

Schematically wire and trace current flow through hot wire, thermal, current, and potential relays for correct operation.

Schematically wire two and three terminal thermal overload protectors for correct operation.

Standard of performance:

The standard of performance for this project is 100 percent completion errorfree.

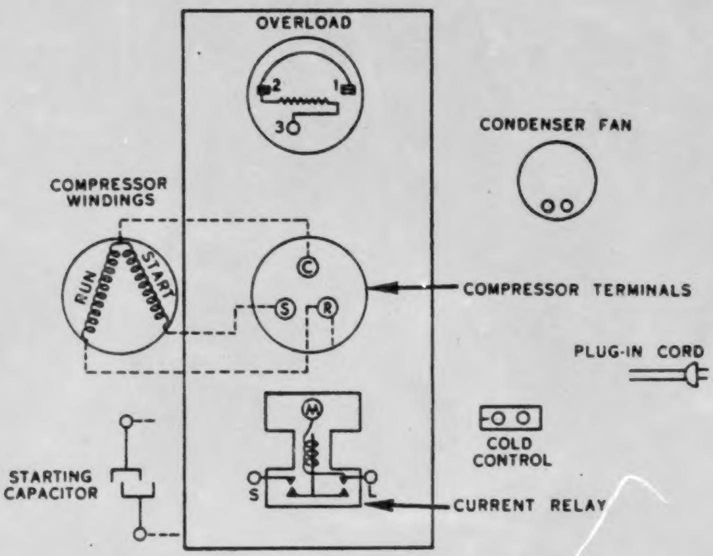
EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-II-2-P1	1/student
Pen or pencil	1/student

PROCEDURE

PART I

1. Complete the wiring diagram shown below and answer the questions that follow the diagram.


OVERLOAD
2
1
3
CONDENSER FAN
COMPRESSOR WINDINGS
RUN
START
C
S
R
COMPRESSOR TERMINALS
PLUG-IN CORD
M
COLD CONTROL
STARTING CAPACITOR
S
L
CURRENT RELAY

Current Relay

2. Does the current relay require the use of the external overload protector?

____

3. Must the condenser fan always be connected to the line side of the protector?

____

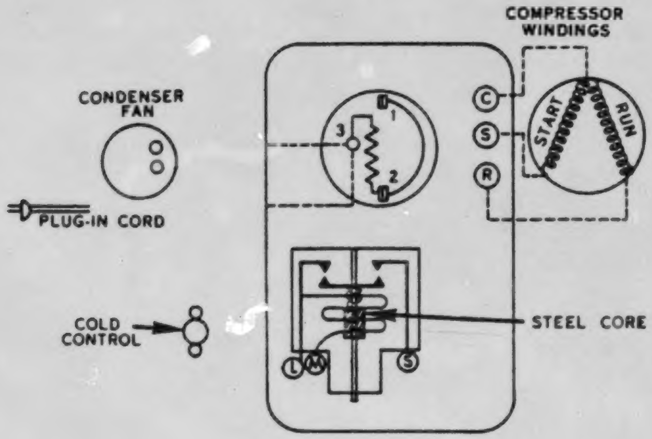
4. Must the starting capacitor always be installed between the contacts of the relay and the compressor? ______________

5. Is the relay operated by voltage or the run winding current? ______________

6. Are the contacts normally open or normally closed? ______________

PART II

1. Complete the wiring diagram shown below and answer the questions that follow the diagram.


COMPRESSOR WINDINGS
CONDENSER FAN
PLUG-IN CORD
COLD CONTROL
STEEL CORE
C
S
R
START
RUN
1
2
3
L
M
S

Current Relay

2. The overload protector should carry the current of which single component of the system diagrammed above? ____________________

3. Is the relay in the above diagram sensitive to mounting position? ____________________

4. Does the motor control have to conduct full line voltage and current?

____

5. Do the connections make any difference to the operation of the system if the compressor common terminal is connected to the No. 3 terminal instead of the No. 1 terminal?

____

6. Is the relay diagrammed above classified as open or enclosed? ____________________

7. What is the main disadvantage of the current type relay? ____________________

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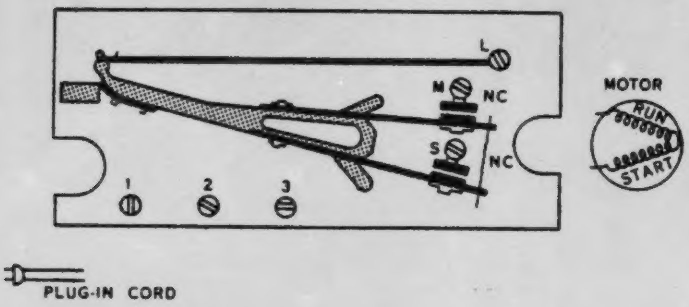
PART III

1. Complete the wiring diagram shown below and answer the questions that follow the diagram.



Hot Wire Relay

2. Does the hot wire relay require an external overload protector?

3. Terminals 1, 2, and 3 serve what function in the operation of the relay?

4. Do the main contacts open to cut out the start winding?

5. What is the purpose of the link that connects the contact sets?

6. Is this relay sensitive to position?

7. Does the ambient air temperature affect the timing of the above type of relay?

8. What causes the contacts to be snap acting when they open?

9. Are the contacts normally open or normally closed?

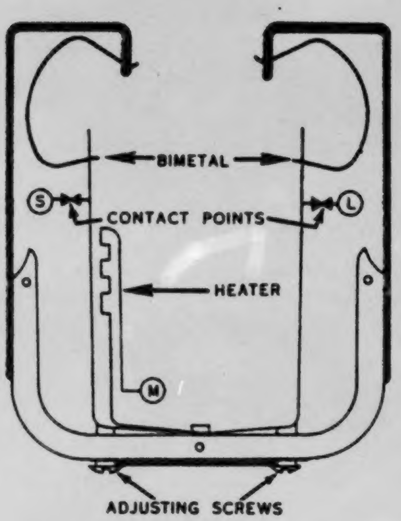
10. Which contacts open to protect the compressor motor if the motor is overloaded?

3B-75-621

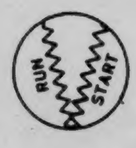
338

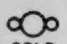
PART IV

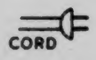
1. **Complete the wiring diagram shown below and answer the questions that follow the diagram.**


BIMETAL
S
L
CONTACT POINTS
HEATER
M
ADJUSTING SCREWS

Thermal Relay


RUN
START
COMPRESSOR


COLD CONTROL


PLUG-IN CORD

2. Does the thermal relay require an external overload protector? ____________________

3. The contact points connected to the "L" terminal will open under what operational conditions? ____________________

4. What causes the starting contacts of the relay to open? ____________________

5. The heater in the relay has which winding current flowing through it? ____________________

6. What is the function of the horseshoe-shaped springs in the relay? ____________________

7. Is the thermal relay position sensitive? ____________________

8. Does the thermal relay have any dummy terminals? ____________________

9. Will the ambient air temperature affect relay's operation? ____________________

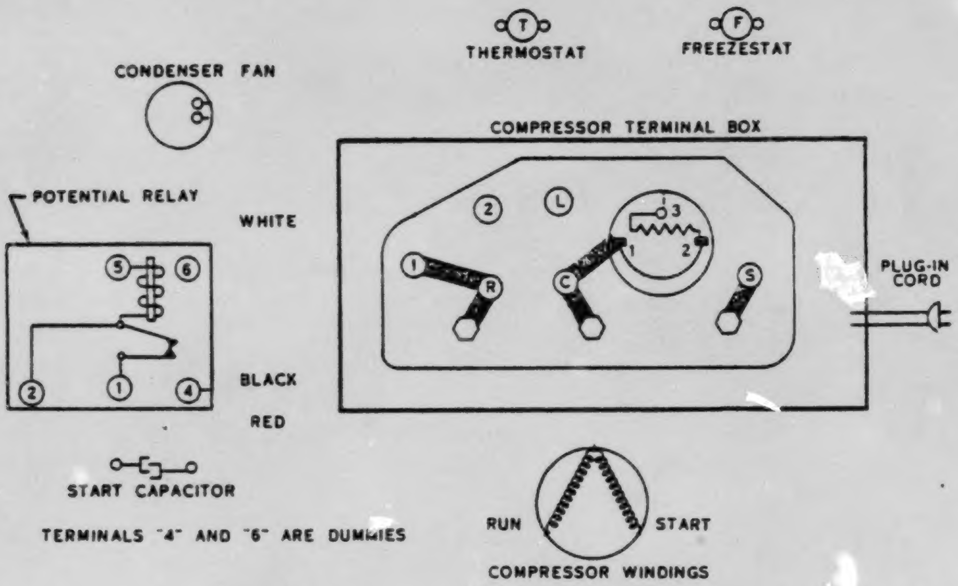
10. Is the thermal relay normally used in high starting torque applications?

____

3F- 75-681

PART V

1. Complete the wiring diagram shown below and answer the questions that follow the diagram.


T
THERMOSTAT
F
FREEZESTAT
CONDENSER FAN
COMPRESSOR TERMINAL BOX
POTENTIAL RELAY
WHITE
2
L
3
1
2
1
R
C
S
5
6
2
1
4
PLUG-IN CORD
BLACK
RED
START CAPACITOR
TERMINALS "4" AND "6" ARE DUMMIES
RUN
START
COMPRESSOR WINDINGS

Potential Relay

2. Is the potential relay operated by heat or by voltage? ______

3. Can terminals No. 4 and No. 6 be used as dummy terminals? ______

4. Does the potential relay require an external overload protector? ______

5. Does the potential relay require the use of a starting capacitor? ______

6. Why is the capacitor required? ______

______

______

7. Must the capacitor be installed before the relay contacts or after (between the relay and the start winding) the contacts? ______

8. Voltage from which winding is used to open the relay contacts ______

______

9. Why does the operating coil require a higher than line voltage to energize the coil sufficiently to open the contacts? ____________________

____

10. Why is the potential relay normally used in high starting torque applications?

____

____

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

ANALYZING HERMETIC COMPRESSORS

OBJECTIVES

Upon completion of this project you will be able to:

Check the compressor motor for opens or shorted motor windings.

Determine the RUN, COMMON, and START terminals of a hermetic motor-compressor assembly.

Use the motor starting cord and motor start analyzer to check the compressor for operable condition.

Standard of performance:

The standard of performance for this project is 100 percent completion errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-II-2-P2	1/student
Trainer, Hermetic Compressor	1/12 students
Multimeter	1/12 students
Motor start cord	1/12 students
Motor start analyzer	1/12 students
Pen or pencil	1/student

PROCEDURE

PART I

DETERMINE COMMON, START, AND RUN TERMINALS OF A HERMETIC COMPRESSOR

1. Obtain a multimeter from the tool cabinet.
2. Select a hermetic compressor as directed by the instructor.
3. Set up and check the multimeter to read resistance.
4. Draw a picture of the terminal arrangement.
5. Check the winding for opens.
   - a. What did the meter read? ____________________
   - b. What does this reading mean? ____________________
6. Check the windings for grounds.
   - a. What did the meter read? ____________________
   - b. What does this reading mean? ____________________
7. Number the terminals in your drawing 1, 2, and 3.
8. Use the multimeter and take reading across each set of terminals. Record the reading in the spaces provided below:
   - a. 1 and 2 = ____________
   - b. 1 and 3 = ____________
   - c. 2 and 3 = ____________
9. The highest reading is the ____________ and ____________ terminals.
10. The lowest readings are the ____________ and ____________ terminals.
11. The middle reading is the ____________ and ____________ terminals.
12. Why must the middle and lowest readings equal the highest reading? ____________

    ____

    ____
13. Label the terminals in your drawing R, S, and C, representing run, start, and common.

Checked by ____________________
Instructor

PART II

COMPRESSOR ANALYSIS

INTRODUCTION: Normally you will use a motor start-analyzer to troubleshoot starting relays. However, if a motor start-analyzer is not available it will be necessary to use other types of testing equipment.

1. CHECKING A STARTING RELAY (Using a plug-in cord and jumper wire).

   Condition: Compressor will not start. The switch is on and electricity is available at the starting relay.

   a. Possible Troubles:

      (1) Starting relay faulty.

      (2) Compressor burned out.

   b. Checking Procedures:

      (1) Remove the electrical connectors at the compressor terminals.

      (2) Determine the common, run, and start terminals.

      (3) Connect the plug-in cord to the "common" and "run" terminals.

      (4) Plug in the cord.

      (5) Momentarily place a jumper wire between the "run" and "start" terminals. Make sure the jumper wire is insulated.

      CAUTION: The jumper wire must not be left in place more than one second.

      (6) Did the compressor start? ______________________

      (7) What would happen if you placed the jumper wire between the "common" and "run" terminals? ______________________

      (8) Place a clamp-on ammeter around one of the electrical conductors.

      (9) What is the amperage draw? ______________________

      (10) What is the amperage draw on the data plate? ______________________

(11) An excessive amperage draw will indicate:

(a) ______________________________

(b) ______________________________

(c) ______________________________

(12) The following conditions can be determined from the information gained in the above tests.

(a) ______________________________

(b) ______________________________

(c) ______________________________

(13) Unplug and remove the plug-in cord.

(14) Replace the electrical connection on the compressor terminals.

(15) Have the instructor check your work.

Checked by ______________________________
Instructor

2. CHECKING A STARTING RELAY (Using a pushbutton starter cord.)

NOTE: All refrigeration specialists should have a pushbutton starter cord. It is much handier and less dangerous than using a plug-in cord and jumper wire.

a. Conditions and Possible Troubles:

The same as with the plug-in cord and jumper wire.

b. Checking Procedures:

(1) Remove the starting relay.

(2) Connect the terminals of the starting cord to the compressor.

(a) "Red" lead to the ____________________ terminal.

(b) "Black" lead to the ____________________ terminal.

(c) "White" lead to the ____________________ terminal.

(3) Plug in the starting cord.

(4) Push the pushbutton.

(5) Did the compressor start? ______________________________

(6) This indicates the relay is ______________________________

(7) Draw a schematic of a compressor and pushbutton starter cord. Label the compressor windings, terminals, electrical leads, and starting switch.

(8) Use the clamp-on voltmeter and check the voltage drop between the unit and ground.

(9) What is the purpose of Step 8? ______________________________

____

____

(10) Unplug the starting cord.

(11) Replace the starting relay.

(12) Replace all your tools and equipment.

Checked by ______________________________
Instructor

3. FAMILIARIZATION WITH ANALYZER

a. Locate each of the following parts of the analyzer:

(1) Hermetic unit terminal color chart.

(2) Test lamp for checking continuity.

(3) Pushbutton for applying power to the analyzer.

(4) Rocker switch for reversing the motor.

(5) Bank of capacitors and switches.

(6) Three clips for connection to a sealed unit.

(7) Plug for connection to an electrical outlet.

b. Go to the hermetically sealed unit assigned you and complete the following tests.

4. TEST MOTOR WINDINGS FOR CONTINUITY

a. Insert any two (2) of the plugs in jacks Number 2 and 3 on motor-start analyzer.

b. Connect the analyzer to a source of electrical power.

NOTE: To check power to the motor start analyzer, turn power switch on and depress pushbutton switch. If power is available, the test lamp on the analyzer will light.

c. Remove wiring from the refrigeration unit. Refer to color chart and locate the "start," "run," and "common" terminals. (Use bench compressors.)

d. Place one test clip on the "common" terminal. Touch the other clip to the "start" terminal, if the test lamp on the analyzer lights, the starting winding is good.

e. Repeat the above test using the "common" terminal again and touching the second lead to the "run" terminal.

The above tests indicated ____

____

5. TEST FOR GROUNDED WINDINGS

a. Set up motor start analyzer by inserting any two plugs into jacks Number 2 and 3.

b. Clip one lead to the motor-compressor case. Make sure it is making good contact.

c. Turn power switch ON.

d. Take the other clip and touch the "run," "start," and "common" terminals successively. If the lamp does not light, the windings are not grounded to the motor-compressor case.

The above test indicated that the winding(s) ______________________________

____

6. START THE UNIT WITH THE ANALYZER

a. Plug the analyzer into a power source and press the pushbutton. The lamp should light giving an indication of power.

b. Disconnect all leads from the refrigeration unit.

c. Connect the clips to terminals corresponding in color to the leads.

d. Refer to the color chart and insert the plugs into the analyzer in accordance with the color chart.

e. Remember, when you are starting the unit with the analyzer you are bypassing the starting relay, and with capacitor start motors, you must use the capacitor in the motor start analyzer.

4P-75-621

WIRING COMMERCIAL SYSTEMS

OBJECTIVES

Upon completion of this project you will be able to:

Wire a magnetic line starter with line, load, and control circuits for correct operation.

Wire temperature motor controls; high and low pressure motor controls, and compute the adjustments required to maintain the desired conditions.

Wire an oil safety control and compute the adjustment required to provide adequate protection.

Wire an automatic defrost control system and compute adjustments required to assure proper defrosting.

Standard of performance:

The standard of performance for this project is 100 percent completion errorfree.

EQUIPMENT

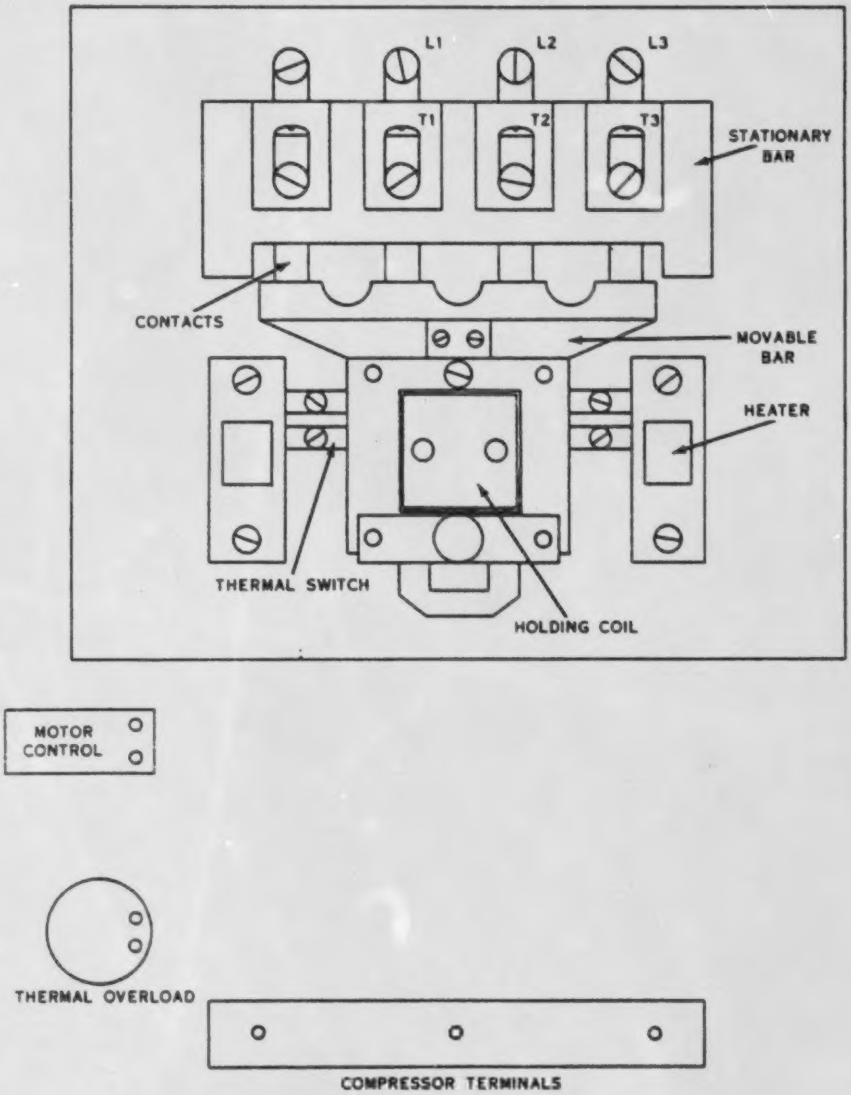
	Basis of Issue
WB 3AZR54550-2-II-2-P3	1/student
Pen or pencil	1/student

PROCEDURES

PART I

MAGNETIC LINE STARTER WIRING

1. **Study the components in the illustration below.**
2. **Using the diagram, connect all the components of the system to represent the wiring.**


L1
L2
L3
T1
T2
T3
STATIONARY BAR
CONTACTS
MOVABLE BAR
HEATER
THERMAL SWITCH
HOLDING COIL
MOTOR CONTROL
THERMAL OVERLOAD
COMPRESSOR TERMINALS

Motor Starter

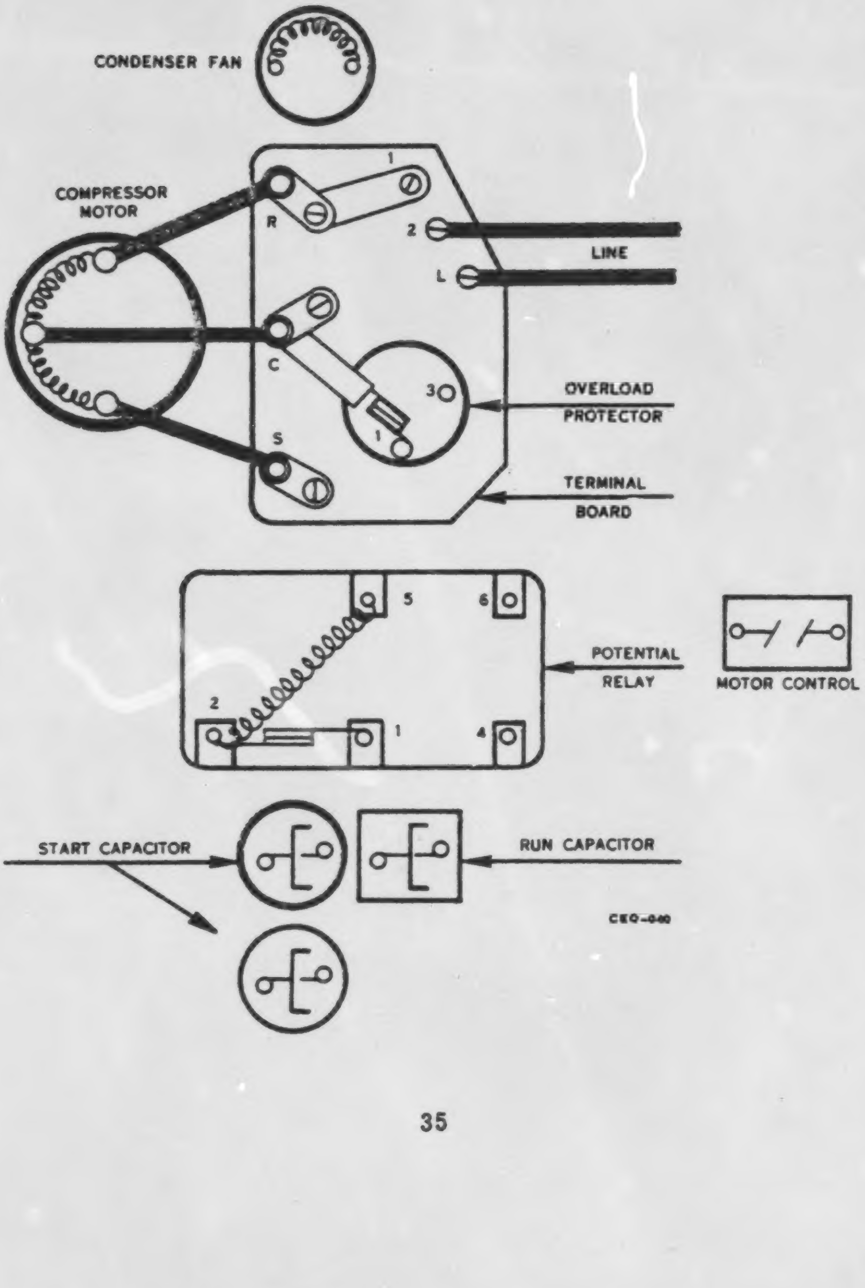
PART II

TEMPERATURE MOTOR CONTROL AND PRESSURE MOTOR CONTROL ADJUSTMENTS

NOTE: The electrical diagram shown below is a temperature type motor control used in a display case.

1. Complete the wiring diagram based on a temperature type motor control.

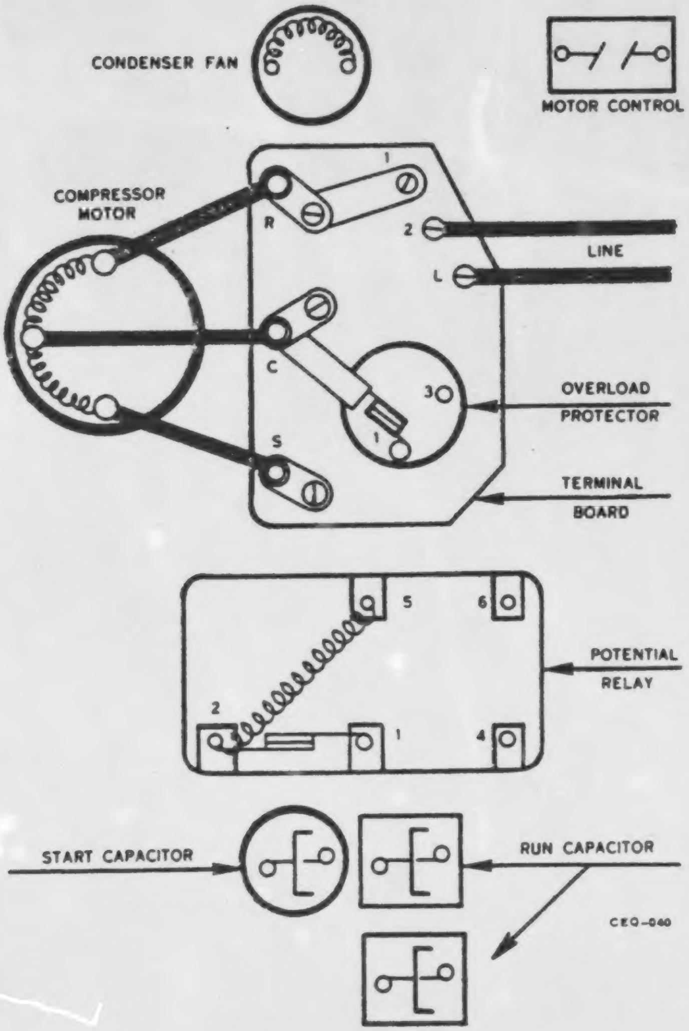
DISPLAY CASE ELECTRICAL SYSTEM


CONDENSER FAN
COMPRESSOR MOTOR
1
R
2
LINE
L
C
3
OVERLOAD PROTECTOR
1
S
TERMINAL BOARD
5
6
2
1
4
POTENTIAL RELAY
MOTOR CONTROL
START CAPACITOR
RUN CAPACITOR
CEO-040

2. Complete the wiring diagram below based on the use of a combination high/low pressure type motor control.

NOTE: The motor control used in the diagram below is the low pressure/high pressure combination type.

DISPLAY CASE ELECTRICAL SYSTEM


CONDENSER FAN
MOTOR CONTROL
COMPRESSOR MOTOR
1
R
2
LINE
L
C
3
OVERLOAD PROTECTOR
1
S
TERMINAL BOARD
5
6
POTENTIAL RELAY
2
1
4
START CAPACITOR
RUN CAPACITOR
CEO-040

3. Compute adjustments to maintain desired temperature in the Display Case.

PART III

ADJUSTING MOTOR CONTROLS ON COMMERCIAL REFRIGERATION UNITS

NOTE: There are several different manufacturers producing both pressure and temperature motor controls that are used on various types of commercial refrigeration units. If you understand the principles of operation and adjustment of one manufacturer's controls, you can figure out any of the others very easily.

PROBLEMS:

Adjust the motor control to maintain a temperature of 15° to 25° in a walk-in box (assume an evaporator TD of 10° unless otherwise stated).

1. Draw a condition chart as illustrated.

	Box Temp	Evap Temp	Suction Pressure
Cut-in			
Cut-out			

Condition Chart

2. Place the required cut-in and cut-out temperatures in their respective places. In this case, the cut-out is 15 and the cut-in is 25.

   NOTE: At cut-in, the evaporator temperature and box temperature will be the same (the evaporator fan continues to operate and the compressor is off).

3. Place 25° under evaporator temperature.

   NOTE: At cut-out, the evaporator temperature is 10° less than the box temperature. This is due to the fact that we are using a 10° TD evaporator.

4. Place 5° under evaporator temperature.

5. Use your pressure-temperature relationship chart and look up the refrigerant (R-12) pressures for 25° and 5°. In this case, it is 24.6 and 11.7, respectively.

6. Place 24.6 and 11.7 in the condition chart.

7. Subtract 11.7 from 24.6; this gives you the pressure differential. It is 12.9.

   NOTE: Up to this time, we have not considered the type of manufacturer of the motor control being used. With the information available in the condition chart, we can adjust any type of motor control to maintain the required temperatures.

8. Fill in the blanks for the following controls.

PENN

	Box Temp	Evap Temp	Suction Pressure
Cut-in			
Cut-out			

RANCO

	Box Temp	Evap Temp	Suction Pressure
Cut-in			
Differential			

9. Have the instructor check your work.

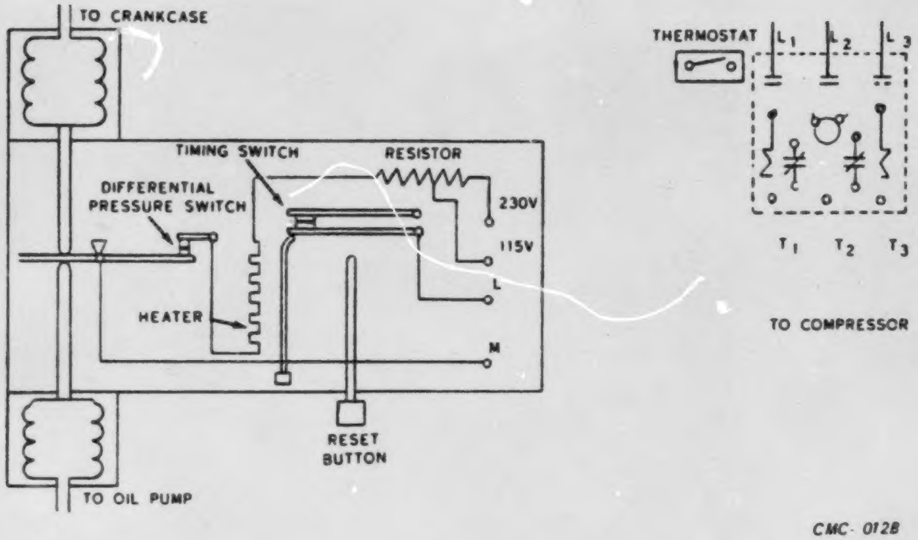
Checked by_______________________
Instructor

SP- 75-621

PART IV

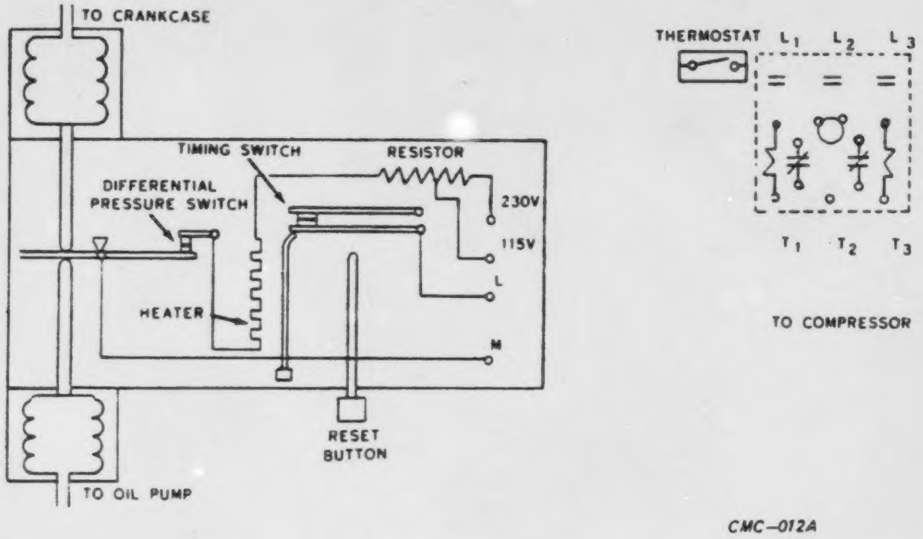
WIRING OIL PRESSURE SAFETY SWITCH

1. Study the components in the diagram below.
2. Complete the wiring for a three-wire oil pressure switch.


TO CRANKCASE
TIMING SWITCH
RESISTOR
DIFFERENTIAL PRESSURE SWITCH
230V
115V
L
HEATER
M
RESET BUTTON
TO OIL PUMP
THERMOSTAT
L1
L2
L3
T1
T2
T3
TO COMPRESSOR
CMC- 012B

Three-Wire Oil Pressure Safety Switch

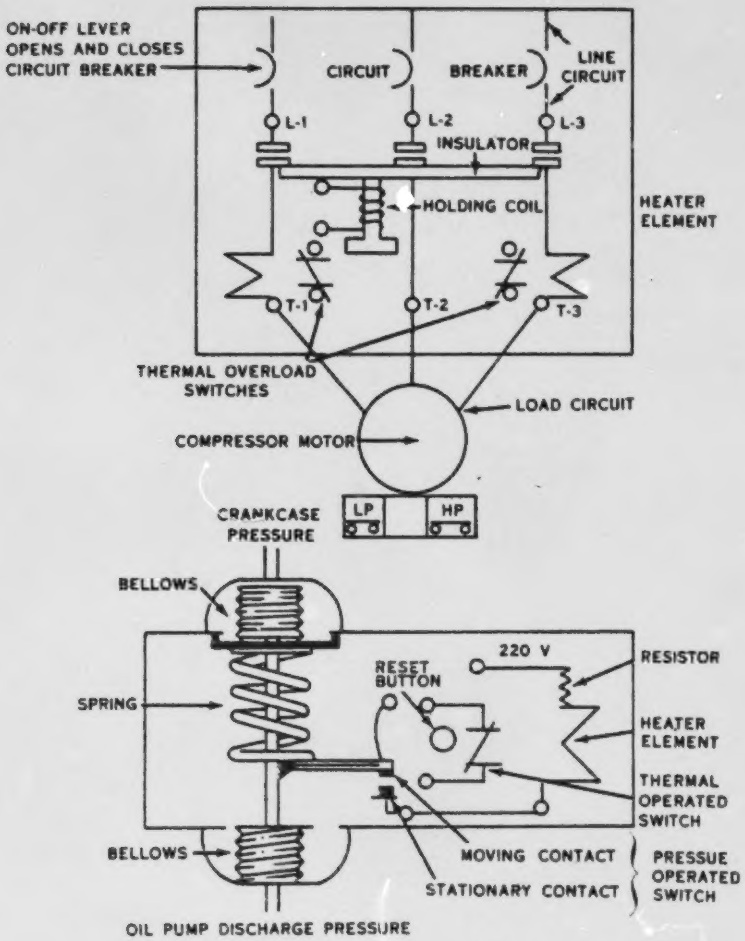
3. Study the components in the diagram on page 40.
4. Complete the wiring for a four-wire oil pressure switch.


TO CRANKCASE
TIMING SWITCH
RESISTOR
DIFFERENTIAL PRESSURE SWITCH
230V
115V
L
HEATER
M
RESET BUTTON
TO OIL PUMP
THERMOSTAT
L1
L2
L3
T1
T2
T3
TO COMPRESSOR
CMC—012A

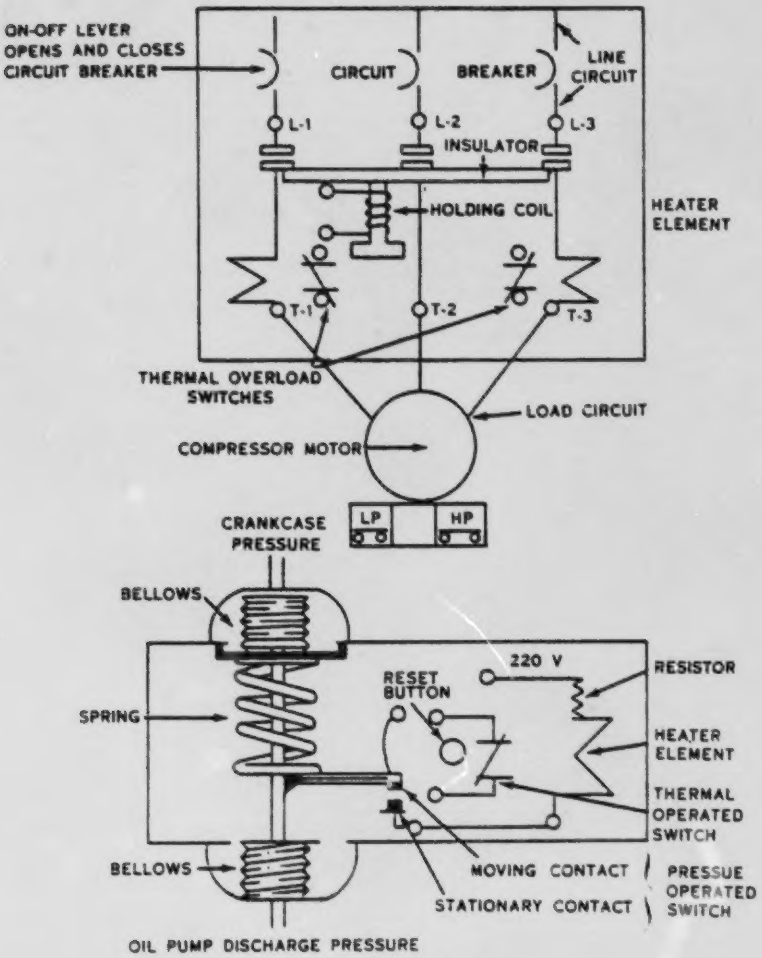
Four-Wire Oil Pressure Safety Switch

5. Use a red pencil and connect the units of the control circuit in series.

6. Use a blue pencil and connect the units of the pressure operated circuit in series.


ON-OFF LEVER OPENS AND CLOSES CIRCUIT BREAKER
CIRCUIT
BREAKER
LINE CIRCUIT
L-1
L-2
L-3
INSULATOR
HOLDING COIL
HEATER ELEMENT
T-1
T-2
T-3
THERMAL OVERLOAD SWITCHES
LOAD CIRCUIT
COMPRESSOR MOTOR
LP
HP
CRANKCASE PRESSURE
BELLOWS
220 V
RESISTOR
RESET BUTTON
SPRING
HEATER ELEMENT
THERMAL OPERATED SWITCH
BELLOWS
MOVING CONTACT
STATIONARY CONTACT
PRESSUE OPERATED SWITCH
OIL PUMP DISCHARGE PRESSURE

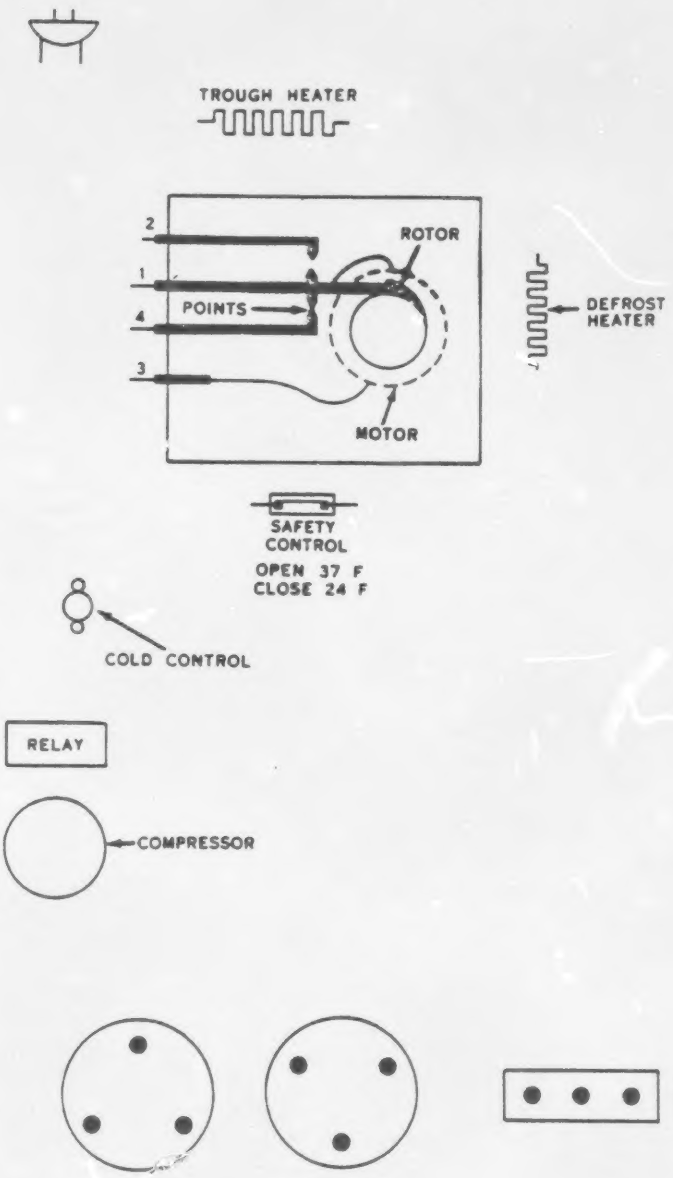
7. Have the instructor check your work on the preceding page. Any corrections should be corrected on the drawing below.


ON-OFF LEVER OPENS AND CLOSES CIRCUIT BREAKER
CIRCUIT
BREAKER
LINE CIRCUIT
L-1
L-2
L-3
INSULATOR
HOLDING COIL
HEATER ELEMENT
T-1
T-2
T-3
THERMAL OVERLOAD SWITCHES
LOAD CIRCUIT
COMPRESSOR MOTOR
LP
HP
CRANKCASE PRESSURE
BELLOWS
220 V
RESISTOR
RESET BUTTON
SPRING
HEATER ELEMENT
THERMAL OPERATED SWITCH
BELLOWS
MOVING CONTACT
STATIONARY CONTACT
PRESSUE OPERATED SWITCH
OIL PUMP DISCHARGE PRESSURE

PART V

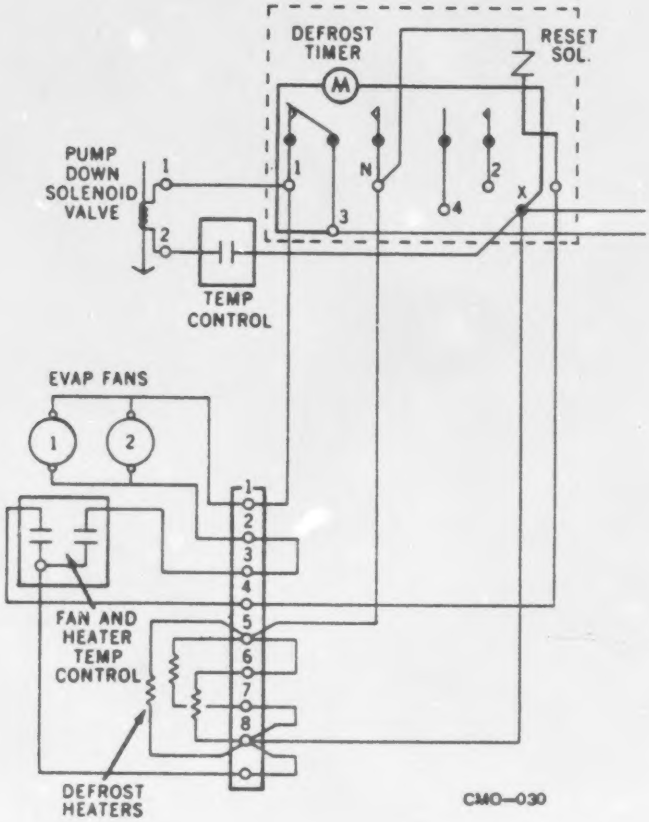
WIRING AUTOMATIC DEFROST SYSTEMS

1. Using a pencil, draw lines to represent wire to the components illustrated below. Upon completion of this you will have wired a defrost system.


TROUGH HEATER
2
1
4
3
ROTOR
POINTS
MOTOR
DEFROST HEATER
SAFETY CONTROL
OPEN 37 F
CLOSE 24 F
COLD CONTROL
RELAY
COMPRESSOR

Automatic Defrost System

INSTRUCTIONS: Answer questions 2 and 3 while referring to the defrost system electrical diagram shown below.


DEFROST TIMER
M
RESET SOL.
PUMP DOWN SOLENOID VALVE
1
2
1
N
3
4
2
X
TEMP CONTROL
EVAP FANS
1
2
1
2
3
4
5
6
7
8
FAN AND HEATER TEMP CONTROL
DEFROST HEATERS
CMO—030

2. What devices will deenergize when the main timer contacts open?

____

____

3. When are the heater elements energized? ________________________

____

OPERATION AND ADJUSTMENT OF MULTI-EVAPORATOR SYSTEMS

OBJECTIVES

Upon completion of this project you will be able to:

Operate and adjust a multiple evaporator system to maintain a different temperature in each space.

Standard of performance:

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-II-2-P4	1/student
Pen or pencil	1/student

PROCEDURE

Accomplish all preoperational checks listed below prior to operation of the trainer and observe the listed procedures closely during all operations.

1. Locate trainer assigned by instructor.

2. Perform preoperational checks for:

   a. Frayed or loose wiring.

   b. Refrigerant line connections for security of fittings.

   c. Master switch for OFF position.

   d. Condenser fan switch for OFF position.

   e. Removal of all obstructions.

3. Operational safety checks.

   a. Wear goggles while operating trainer.

   b. Install manifold gages.

   c. Place suction and discharge service valves in gage position and open king valve.

   d. Observe manifold gage assembly for proper operating pressures.

4. Open the manual bypass valves and turn thermostats to their coldest setting.

   NOTE: This will bypass the evaporator pressure regulator valves and the solenoid valves will remain open.

5. Adjust the pressure control to cut-in and cut-out at a selected box temperature range.

   a. Cut-in__________psi

   b. Cut-out__________psi

6. Operate the system.

7. Check the box temperature with a thermometer.

8. Make adjustments, if necessary, to maintain temperature range.

9. When the pressure in the common suction line reaches the cut-out point on the pressure control, the unit will______________________________

10. It starts again when the suction pressure reaches______________psi.

11. Have instructor check your work.

12. We will now operate the trainer as a solenoid valve multi-temperature system.

13. Adjust the thermostats and pressure control for desired box temperatures.

    a. Box #1______________°F

    b. Box #2______________°F

    c. Box #3______________°F

    Operate the trainer.

14. Have the instructor check your trainer when it cycles on the correct temperatures.

15. The trainer will now be operated as an evaporator pressure regulator system.

16. Close the manual bypass valve.

17. Turn thermostats to their coldest position.

    NOTE: This keeps the solenoid valves in the OPEN position.

18. Service the system for operation.

GR- 75-621

19. Adjust the EPR valves and motor control for desired box temperatures.
    a. Box #1____________°F
    b. Box #2____________°F
    c. Box #3____________°F
20. Operate the trainer.
21. Have the instructor check your trainer as it cuts out at designated temperature settings.
22. Pump system down, using proper procedures.
23. Wear goggles and backseat service valves and remove manifold assembly.
24. Postoperation checks.
    a. Check all switches for OFF position.
    b. Disconnect electrical power supply.
25. Have instructor check your work.

Checked by______________________________
Instructor

33c

SG 3AZR54550-2-III-1 thru 4

Department of Civil Engineering Training

Refrigeration and Air-Conditioning Equipment

AIR-CONDITIONING SYSTEMS

October 1974

SHEPPARD AIR FORCE BASE

11-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

AIR-CONDITIONING SYSTEMS

BLOCK III

(Days 17-25)

UNIT	TITLE	PAGE
III-1	Air Movement, Calculations, and Psychrometrics	1
III-2	Direct Expansion Air-Conditioning Systems	45
III-3	Centrifugal Air-Conditioning Systems	83
III-4	Absorption Systems	155

This supersedes SG 3AZR54550-2-III-1 through 4, 3 January 1973.

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

SG 3AZR54550-2-III-1
3 September 1974

AIR MOVEMENT, CALCULATIONS, AND PSYCHROMETRICS

OBJECTIVES

This study guide will help you to understand the principles of air movement and air movement measuring devices, basics of psychrometric plots, heat load estimates, and calculations used to determine conditioned air requirements for a given space.

INTRODUCTION

If you look at air conditioning carefully, you'll see that air itself is used to condition the occupied space. To properly condition the space, the air-conditioning specialist must be able to analyze the air in the room and then supply the right amount of conditioned air. The heat load must be known to insure the proper rate of heat removal. Heat load estimates give the technician an advanced knowledge of the cooling job to be done.

AIR-CONDITIONING FUNDAMENTALS

Development

To make a study of air conditioning logical and thorough, we should ask "What is air conditioning?" "What has man done to make his environment more comfortable?"

Fire has been used by man in many ways since prehistoric times to help keep him warm. Fireplaces, stoves, furnaces, hot water, and steam boilers each were a forward step from an open fire. Steam boilers, developed to power engines, soon led to the use of the steam heating coil.

During the 1920s, air conditioning used to cool the air began to go into public buildings. This development evolved from the meat packing industry, which was using mechanical refrigeration for cold storage of meats. Cooling coils from these warehouses were installed in offices. It was from these coils that the first forms of mechanical comfort cooling were effected.

The study of moisture in air evolved in the clothing industry. High humidities were essential for clothing manufacturing processes. The majority of the clothing plants were located in seacoast cities. However, even in these locations, days occurred when the weather was dry enough to cause the cloth fibers to become brittle so they could not be handled by machines. The methods used to increase the humidity were to spray water directly into the room or to blow air through spray chambers and then into the room.

Definition of Air Conditioning

The legal definition of air conditioning was developed under the direction of the Federal Trade Commission. The definition was worked out be representatives of all interested industries and states: Air conditioning is the automatic control of temperature, humidity, air motion, and filtering.

The American Society of Refrigeration and Air-Conditioning Engineers goes into a little more detail. They define air conditioning "as the simultaneous control of all, or at least the first three, of those factors affecting both the physical and chemical conditions within any structure." These include: temperature, humidity, motion, distribution, dust, bacteria, odors, and toxic gases which affect human health and comfort.

Let us discuss each of the above points in more detail.

Control of Temperature

The control of temperature means cooling the air when it is too warm and heating it when it is too cold.

The design, installation, and servicing of cooling and heating systems in the past have been done primarily by a specialist trained in the specific area. With the advent of modern, year-round systems, specialists are being required to know enough of the overall system to effectively design, install, and service both modes of operation.

Control of Humidity

When air is cooled below the dewpoint, it will be dehumidified. In an area of high humidity, removal of moisture is much more important than the cooling process. This is commonly done by mechanical refrigeration during the cooling process. The cooling coils are kept cold enough to condense the unwanted moisture from the air. The big problem is to balance the dehumidification against the cooling required.

When air is heated, moisture must usually be added to prevent the air from being too dry. In small systems, this may be accomplished by various types of water pans or water evaporators directly in the furnace housing or in the airstream. Large systems usually require air washers for adding humidity. In industrial applications, water or steam may be sprayed directly into the heated space.

Air Motion

A cooling or heating system is useless if the processed air cannot be distributed to the areas where it is needed. The best system in the world will not give satisfactory results if the air is improperly distributed. Fans and ducts must supply air to all parts of the conditioned space without objectionable drafts. This, of course, requires a thorough knowledge of fans, duct systems, registers or diffusers, and distribution systems.

Air Purity

The refrigeration specialist must know how much fresh air needs to be added to the air recirculated from a space. He must have a knowledge of the common contaminating substances in air such as dust, bacteria, odors, and toxic gases, and their effects. He needs to know how they can be removed and to what degree of purity it is worthwhile to remove them. This knowledge is essential for an air-conditioning specialist to perform effectively.

Automatic Control

All the facts mentioned previously must be put together in a properly coordinated system. The system must then be made to automatically vary the condition of the air as required. It must balance the load of changing temperatures and humidities. It must take into account the number and activity of the occupants in the conditioned space. It must compensate for the effect of lights, motors, appliances, and anything that may add heat to the space. All this must be done smoothly and automatically to keep the occupants comfortable and satisfied.

The best and most expensive air-conditioning plant cannot give the desired results if it is not properly controlled.

AIR-MEASURING INSTRUMENTS

One of the functions of an air-conditioning system is to deliver the proper amount of air to an area at a specific time. It is the air-conditioning specialist's job to know if the system is conditioning properly. There are several instruments on the market that measure the velocity of the air. We will measure the velocity of the air using some of these instruments. There are two basic factors that determine the amount of airflow: the velocity or rate of air movement and the area that it must pass through. When talking about velocity we use the term, feet per minute. There are three types of instruments commonly used in the field to measure airflow.

All of these instruments measure velocity in fpm of airflow. Readings can be taken at the following locations: return air duct (RA), supply air duct (SA), outside air duct (OA), inside the duct system, and at room diffusers, and registers.

Anemometer

The anemometer is an instrument used to measure air velocity in linear feet per second. This meter is composed of the fan housing, three dial faces, and the propeller which is turned by air movement. The propeller drives a gear mechanism which operates the dials. There is an engaging lever and a reset lever on top of the dial face.

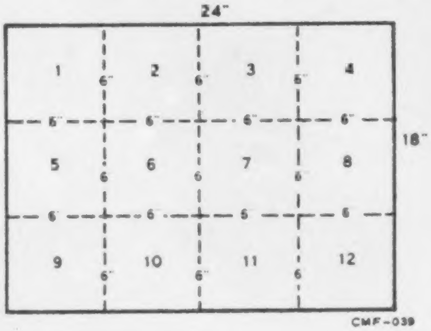


Figure 1. Calculating Duct Surface Area

In using the anemometer, we normally take readings at the duct face. The face should be divided into equal 6" squares. If a duct measured 24" X 18", there would be four 6" squares across the length, and three 6" squares across the height. This gives a total of 12 (4 X 3) equal 6" squares of surface area as shown in figure 1.

At each of these six-inch openings, the anemometer is used for 10 seconds. The resulting time lapse for the total air measurement is expressed as elapsed time and is obtained by multiplying the number of squares by ten. For example: 12 X10 = 120 seconds.

To operate the anemometer, place the instrument into the stream of air being measured. Allow the propeller to reach maximum speed. Then trip the engaging level and hold it in the same location for 10 seconds. Move to the next area(s) and hold for 10 seconds until all of the 6" areas have been measured. Trip the lever to the OFF position.

Read the anemometer by reading the dials in the following sequence:

1. Left dial.
2. Right dial.
3. Center dial (large dial).

If the indicator on the two smaller dials is between any two numbers, take the reading of the lesser number. Read the large dial exactly as indicated on the anemometer in figure 2, the left dial reading is 8000, the right dial reading is 300, and the center dial reading is 80. Therefore, combining the numbers in the proper sequence, the resulting anemometer reading is 8380.

Where the elapsed time is more or less than one minute the following formula is used to convert the anemometer reading to fpm velocity:

$$\text{FPM} = \frac{\text{ANEMOMETER READING (AR) X 60}}{\text{ELAPSED TIME (ET) (in seconds)}}$$

To figure the fpm of the previously discussed duct measurement, the answer would be

$$\text{fpm} = \frac{\text{AR X 60}}{\text{ET}} \text{ or } \frac{8380 \text{ X } 60}{120} = \frac{8380}{2} = 4190 \text{ fpm}$$

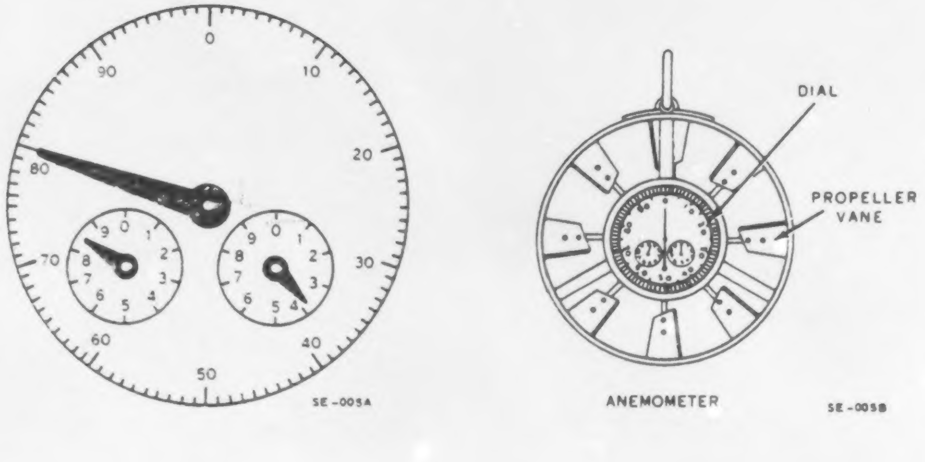


Figure 2. Anemometer Reading (AR)

Inclined Manometer

The manometer family of air-measuring instruments contains various types and styles; however, we will limit the study of manometers to one type, the inclined manometer. The manometer is used to measure the pressure of air in inches of water. Within the duct system, we find two predominant pressures, static and velocity. Static pressure is the outward pressure of air in all directions. Velocity pressure is the force exerted by the movement of air in the direction of flow. Often it is impossible to get the manometer into the airstream to measure the pressure. The pitot tube was developed to allow access to the internal sections of the duct in hard to get to areas. In reality, the pitot tube is a tube within a tube as indicated in figure 3.

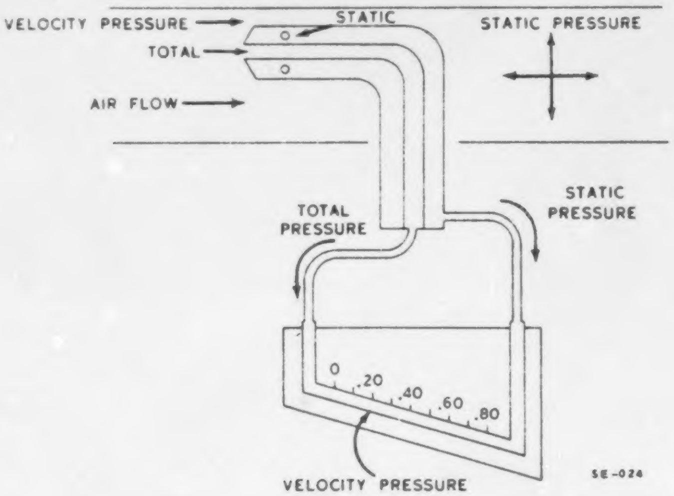


Figure 3. Pitot Tube and Manometer Installed

The pitot tube is inserted into the airstream into the forcing flow. Velocity (total) pressure goes into the center of the assembly to the manometer, forcing the oil column (graduated inclined tube) in the meter downward. The static pressure enters the small ports surrounding the tube to the manometer forcing the column of oil in the meter tube upward. Where the column stabilizes between the opposing pressures, the reading is taken from the graduated scale.

The pressure indicated on the manometer, as connected in figure 3, is known as pressure of velocity. It is represented as PV in the conversion formula used to convert pressure into feet per minute. To convert pressure of velocity into fpm, the following formula is applied:

$$\text{fpm} = \sqrt{PV} \times 4005$$

fpm - the number of feet of air which passes a point in a duct in one minute

$\sqrt{\quad}$ - symbolizes square root

PV - pressure of velocity as read on the inclined manometer

X - multiplied by

4005 - is a standard number based on the velocity of standard air.

Standard air is air at 70°F dry bulb and 14.7 psia (sea level). Standard air weighs .075 lbs per cubic foot. A pound of dry air occupies 13.34 cu ft of space.

Velometer

The velometer used to measure air movement is a rugged mechanical system, soundly engineered for very concise readings. Inside the meter, air impinges on an aluminum vane to move the pointer. This vane travels in a calibrated air chamber or tunnel constructed airtight to provide a desirable scale distribution. The moving system is balanced by counterweights to provide accuracy in all positions. The moving system is equipped with bronze hairsprings and moves on monel pivots which ride in sapphire jewel bearings. Some velometers are equipped with filters to protect them from extreme dust conditions. When a filter is supplied with the instrument, the filter is an integral part of the instrument and must be used. If the filter is left out, the instrument will give a false reading.

To measure velocities at supply openings, attach the proper jet by means of the appropriate tube and tube fittings. To determine the average velocity, mentally divide the opening into a number of equal areas. Take a reading at each of the areas and average the readings. There is no exact rule for the number of readings that must be taken, but the more that are taken, the more accurate the average. It is recommended that a minimum of six readings be used.

To measure the air velocity at the suction opening, connect the proper jet by means of the tube and tube fittings to the right-hand port of the meter. While taking the readings, hold the jet so that it is perpendicular and the tip is in the same plane as the opening. This is very important because the velocity changes very fast in front of a suction opening. To measure velocities inside of ducts, use the duct jet called for in the manual of instructions. The duct jet should be inserted into the left-hand port. Read the scale marked with the number of jet being used.

Calculating Cubic Feet per Minute (cfm)

After establishing the fpm, the cfm for a duct can be established by using the formula:

$$\text{cfm} = \text{fpm X duct area (sq ft) of its cross section or opening}$$

Once the cfm has been established, we can calculate the total pounds of air being added to the space under consideration.

$$\text{lbs of air} = \frac{\text{cfm}}{\text{specific volume}} \text{ or cfm X specific density}$$

NOTE: Remember if no means is provided for finding specific volume, use the value for standard air - 13.34 cubic feet per pound or .075 pound per cubic foot.

After finding the total pounds of air, the total Btu content or the latent and sensible heat content can be calculated using the formula:

Total Btu = lb of air X HCD

Total latent Btu = lb of air X HCD (latent)

Total sensible Btu = lb of air X HCD (sensible)

NOTE: HCD stands for heat content difference.
HCD can be determined mathematically or
by use of the psychrometric chart.

Earlier in this course, you learned to convert total Btu into tonnage by dividing by 12,000. If tonnage is to be found in conjunction with these formulas, substitute 200 Btu/minute in place of the standard 12,000 Btu/hour.

Capacity Check Formula

To find out if the system is performing to designed standards, use the quick check formula for determining output of a unit. This formula is

$$\frac{\text{cfm} \times .075 \times \text{HCD}}{200 \text{ Btu/min}} = \text{Tonnage}$$

AIR DISTRIBUTION

Air distribution systems direct the air from the air-conditioning equipment to the conditioned space and return it to the equipment. The simplest combination of fan, duct, and outlets usually result in the best system. The more elbows, dampers, and fittings in the duct system, the more complex it becomes.

Air is moved by mechanical means in an air-conditioning system. This is accomplished by means of a wheel or blade imparting a force on the air so that it will leave the air moving assembly in a forward motion to reach a desired destination. Fans are classified into two major categories: axial and radial.

Types of Fans

AXIAL FANS. These fans move air in a flow parallel to the shaft. The air will have a spiral motion but will be moving in a parallel plane. Axial fans have three blade classifications.

Propeller Fan Blades. Propeller fan blades are found on the pedestal or table fan common to home use. Fans of the ceiling variety use propeller blades. These fans are used to move air within a given area (circulation). Normally they have a safety shroud around them and operate satisfactorily against static pressures of 1/2 to 2/3 inch water pressure. They can be used only if low pressure air movement is required and normally are used for exhaust or ventilation purposes. They can be direct drive or belt-driven, see figure 4.

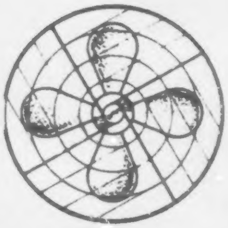


Figure 4. Propeller Fan

Tube-Axial Fans. These fans are used for heavier duty air movement. They are built for mounting in duct work; whereas the propeller type is mounted anywhere it is convenient such as in a wall or on a pedestal. Since the air moves at a higher velocity, the increase of the spiral movement incurs greater duct pressure losses and increases the amount of noise in a duct system. For this reason, they are normally used for industrial applications where noise is a minor consideration. The tube-axial fans can develop pressures up to 1 1/2 to 3 inches of water pressure. They are also direct or belt driven. The propeller fans of all types have the added characteristic of using the most power at maximum air delivery, see figure 5.

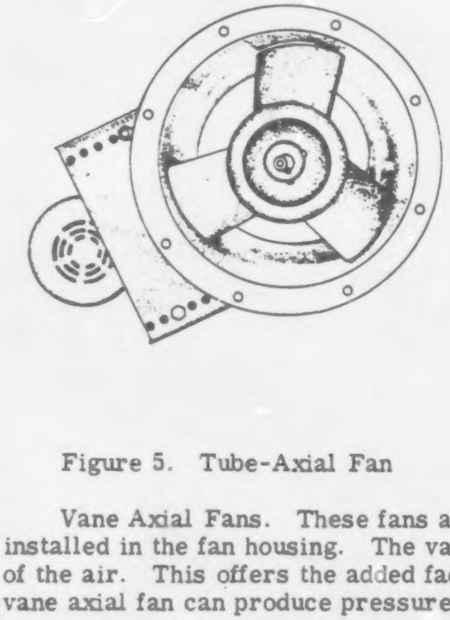


Figure 5. Tube-Axial Fan

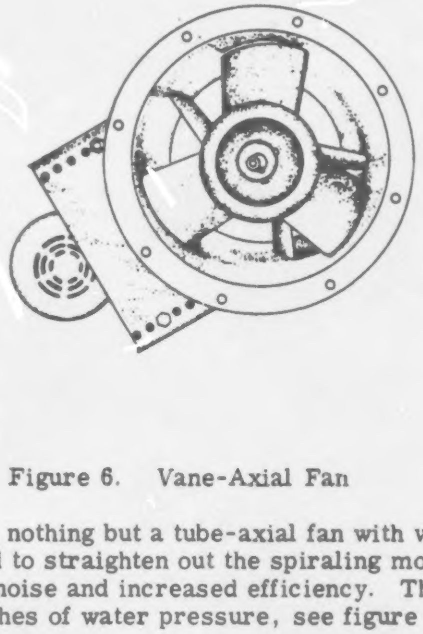


Figure 6. Vane-Axial Fan

Vane Axial Fans. These fans are in reality nothing but a tube-axial fan with vanes installed in the fan housing. The vanes are used to straighten out the spiraling motion of the air. This offers the added factor of less noise and increased efficiency. The vane axial fan can produce pressures up to 3 inches of water pressure, see figure 6.

RADIAL FANS. Radial fans move air by drawing it in parallel to the shaft but discharging it vertically or radially to the shaft, figure 7. This means that the air is discharged at a 90° angle or plane from the shaft of the fan. The centrifugal or radial fan consists of a wheel (sometimes called a squirrel cage) mounted horizontally on a shaft. which rotates within a housing. Air enters parallel to the axis through the fan housing. The air may enter at either one or both ends of the wheel axis. The centrifugal fan operates with less noise but consumes more power under maximum air delivery as compared to an axial fan. Air-conditioning specialists often refer to centrifugal fans as blowers.

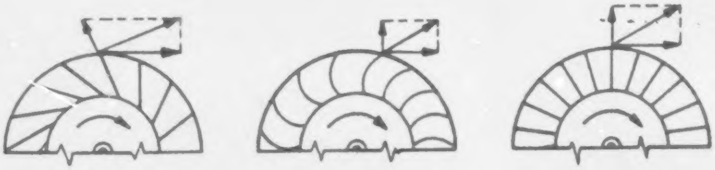


Figure 7. Fan Blades

There are a number of factors which are used in the determination of the fan type to be used for a particular application. They include:

- Unit size
- Drive motor selected
- Internal layout of the unit
- Shape of the coil
- Resistance of system ducts

Fans are used to ventilate (induce fresh air), circulate the same air in a system, or exhaust odor-laden air which is part of the ventilation-circulation process.

Classification of Ducts

Ducts are available in square, rectangular, and round shapes. Economically, round ducts are preferred because they carry the most air in less space. Rectangular ducts may be preferred because they conform better to the (building) design and where there are space limitations. In many systems, rectangular ducts are used for the plenum section and round ducts are used for branch runs.

Ducts are made from a variety of materials such as sheet steel, aluminum, fiberglass, tile, and cement. Each has advantages and disadvantages. For example, sheet steel is heavier than aluminum but it costs less. Aluminum and fiberglass are not as apt to corrode. Tile ducts may be more suitable to slab-type construction. It will depend on the application as to what type duct system is installed.

Air Outlets

Many types of outlets are available and are designed to provide proper control of the distribution of air or the return of air from the room.

SUPPLY OUTLET. A wall, ceiling, or floor opening through which air is delivered to a room.

RETURN OUTLET. A wall, ceiling, or floor opening through which air is exhausted or returned to the unit.

GRILLE. An outlet without a control damper which is usually used on return air or exhaust systems.

REGISTER. A register is a grille which has a control damper to control airflow.

DIFFUSER. A diffuser is an air delivery device so arranged as to promote a mixing of air entering the room.

BASIC PSYCHROMETRICS

Air is the primary medium that is used to control the conditions in the controlled space. Air can be used to control the humidity and temperature for three general uses: personnel or comfort cooling, equipment cooling, and process cooling. New applications for air conditioning are continually being found.

The purpose of air conditioning is the control of temperature, control of humidity, filtration of the air, and air movement.

The field of psychrometric study is a breakdown of the various properties contained in the air and a graphic analysis of the air conditions. If the specialist understands all he can about the air being used, the understanding of the equipment operation becomes more realistic.

Psychrometrics is defined as the study of air and its related properties. As you know, air contains some moisture (humidity). However, let us consider the other properties relating to graphic analysis of moisture laden air. Air is a mixture of highly superheated gases. About 78 percent of the air is nitrogen, 21 percent oxygen, and the remaining one percent is composed of minute quantities of other gases such as carbon dioxide, argon, neon, ozone, hydrogen, helium, and krypton. All of these form the air that we breathe, and use for air conditioning. Air exerts a force of 14.7 psia on the surface of the earth at sea level. Air and water vapors are mixed, occupying the same space and following Dalton's law of partial pressure. "The pressure of a mixture is the sum of the partial pressures of the constituent gases. . ." Vapor pressures are regulated by the movement of the molecules at the surface of the substance. For example, water at a temperature of 212°F has a vapor pressure of 14.7 psia.

Temperature of the Air

Temperature is the measurable heat contained in a volume of air, read in degrees. It can be expressed as degrees Fahrenheit or centigrade, depending on the scale being used. In the psychrometric analysis, such temperatures as dry bulb, wet bulb, dewpoint, saturation, and apparatus dewpoint temperatures are considered.

Humidity of the Air

Humidity is the moisture vapor contained in the air. There are, generally speaking, two humidity expressions: specific humidity and relative humidity. Specific humidity is the actual moisture contained in the air or the grains of moisture content. Relative humidity is an expression of the specific humidity in relation to the volume.

Heat Content of the Air

This term refers to the heat contained in air at a given condition. It is measured in British thermal units (Btu). It is also expressed as the enthalpy. Remember, that a Btu is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. Based on this standard are other standards such as one ton of refrigeration. We know that ice absorbs heat when it melts. One ton of ice requires 288,000 Btus to melt. If a ton of ice melts in 24 hours, it absorbs heat at the rate of 12,000 Btus/hr, 200 Btus/min, or 3.33 Btus/sec. Any of these values equals one ton of refrigeration.

Volume of the Air

Air, as any substance, must occupy space. This space is volume, and is expressed in cubic feet. The volume of air or its pressure varies with the heat contained. As the temperature increases so does the volume, provided room for expansion exists. If there is no room for expansion, the pressure increases due to the limitations imposed by the container.

In the case of unconfined air, the pressure remains constant. The air volume changes with the heat content. A volume of air contracts or expands 1/460 of its volume at 0^{O}F for each degree of temperature change. If absolute zero (-460^{O}F) was reached, the volume would shrink to zero as well. Although this is strictly theoretical and has never been achieved, it does point out the relationship of temperature to volume. Specific volume is the number of cubic feet of air that it takes to weigh one pound.

Weight of the Air

If the air has all of the foregoing properties, then it must be concluded that it has weight. This weight is referred to as specific density (SD). The psychrometric chart will provide the basis for computing the density. The specific volume is known as cubic feet of air per pound of dry air. The weight of the air is dependent on the amount of moisture contained in the air. We will use the constant of one (1) which is divided by specific volume (SV) obtained from the chart. If the SV is 13.34 cu ft then the SD will be .075

$$13.34 \overset{.075}{\overline{\smash{)}1.}}$$

It can be noted that as the specific volume increases, the density of the air decreases.

NOTE: SD of .075 is an accepted industry standard for normal temperature air.

PSYCHROMETRIC CHART.

The psychrometric chart is the tool used to analyze the relationship of the properties of the air. The specialist should master at least the meaning of the chart to properly understand the air that is being conditioned.

The relationship of the properties of the air are graphically illustrated on the psychrometric chart as a series of lines and curves that have been scientifically formulated to show the whole picture of the air being studied.

The comparison of the lines and curves at intersecting points of the scales on the chart gives us a very comprehensive analysis of the air being studied. More than one condition may appear on the chart to give us more accurate analysis and true operation of the system in consideration.

Sling Psychrometer

The sling psychrometer is the instrument that is most often used to obtain the basic values needed to work a psychrometric problem. The sling psychrometer, see figure 8, is an instrument that is very basic in design and operation. There are two standard thermometers mounted on a holder with provisions for the device to be whirled in the air. One of the thermometers has a sock attached to the bulb, which is moistened in distilled water prior to slinging of the instrument. The slinging of the instrument will pick up two temperatures. One is ambient or dry bulb temperature; the second is wet bulb temperature.

The operation of the psychrometer is very simple. The wet bulb sock is saturated with distilled water (because there are no mineral deposits in the water that will form residual scale deposits following evaporation). Then the instrument is whirled in front of the individual for about 30 seconds, read and then whirled for another 15-30 seconds and read a second time.

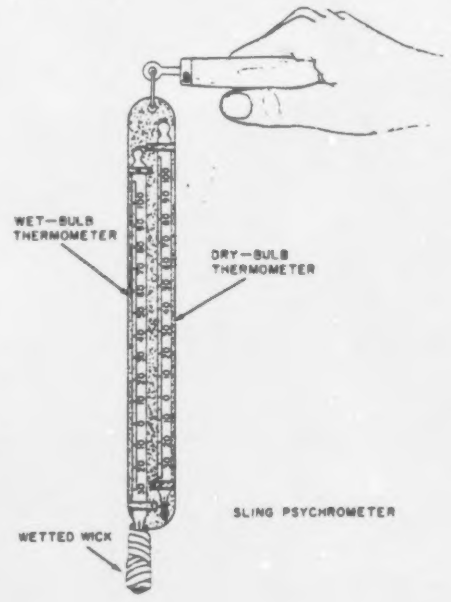


Figure 8. Sling Psychrometer

During this process, air passing through the sock causes evaporation. The evaporation cools the wet bulb thermometer below the dry bulb temperature. The amount of cooling depends on the amount of moisture that is in the air being measured. The drier the air, the higher the evaporation rate, which increases the difference in temperature.

The reason for taking more than one reading is to insure the maximum reading is attained.

The difference between wet bulb temperature and dry bulb temperature is known as wet bulb depression.

Psychrometric Chart Scales

Once the dry bulb temperature and wet bulb temperature have been obtained, they can be plotted on the psychrometric chart. To know what we are doing, we must learn the scales that are read on the psychrometric chart. The psychrometric chart contains numerous connecting lines and curves which have corresponding scales. These lines and curves are read at intersecting points.

In figure 9, the scales are identified. Figures that accompany the explanation of terms and definitions point out the names of the lines corresponding to each set of scales. There are five scales that are used on the psychrometric chart. Some of the readings are scale differential readings.

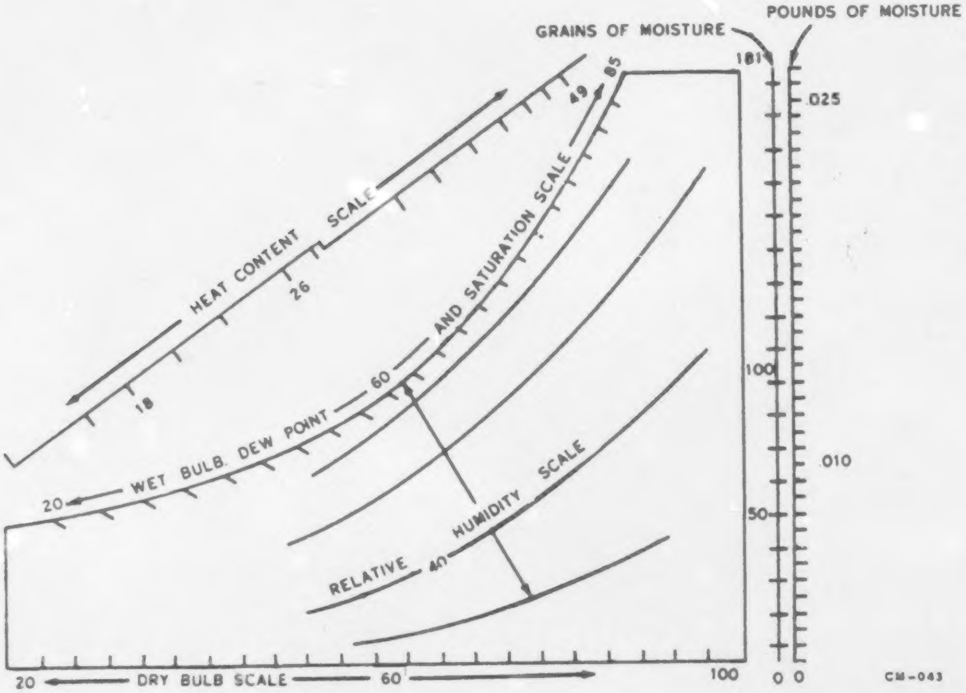

POUNDS OF MOISTURE
GRAINS OF MOISTURE
181
.025
49
85
HEAT CONTENT SCALE
26
18
AND SATURATION SCALE
60
WET BULB DEW POINT
20
100
.010
50
RELATIVE HUMIDITY SCALE
40
20
DRY BULB SCALE
60
100
0
0
CM-043

Figure 9. Psychrometric Chart Scales

TERMS, DEFINITIONS, AND PLOTS

Dry Bulb Temperature (DB)

Dry bulb temperature is the ambient air temperature read on a standard thermometer. Dry bulb plots will appear on the vertical lines of the chart which correspond to the dry bulb scale located along the bottom of the graph. Dry bulb is plotted by locating the indicated condition on the scale, and drawing a vertical line corresponding to the temperature value as shown by the heavy line in figure 10.

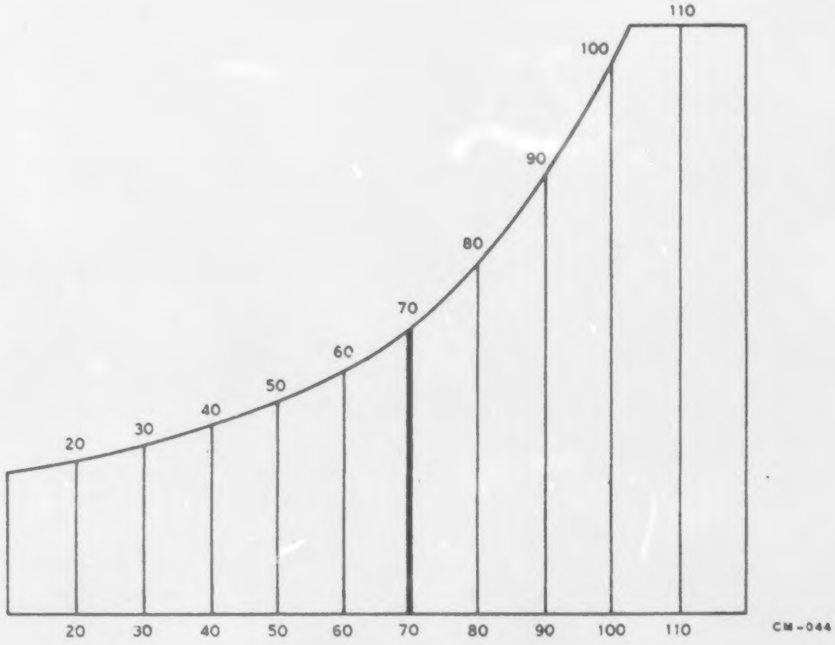


Figure 10. Dry Bulb Line

Figure 10 is a representative sketch of the dry bulb temperature portion of a psychrometric chart. A complete psychrometric chart has a vertical line for each degree of temperature. Usually, every fifth line is numbered with its corresponding temperature. The common range for a psychrometric chart is from about 20°F to 105°F. This type of arrangement makes it simple to plot any dry bulb temperature on the chart to the nearest degree. The remaining figures in this series are also sketches and do not include all the lines on the psychrometric chart.

Wet Bulb Temperature (WB)

Wet bulb temperature is the temperature at which air ceases to be cooled by the process of evaporation. Wet bulb temperature is determined by the sling psychrometer previously described. Keep in mind that the sling psychrometer can only be used effectively if the ambient temperature is above 32°F because water freezes at any temperature below that point. You will notice the slope of the psychrometric chart changes to smaller increments as temperature drops in intensity. Wet bulb temperature is plotted from the temperature values given on the saturation or wet bulb scale. To plot a wet bulb temperature, start with the corresponding temperature reading on the wet bulb scale. The wet bulb temperature is plotted on the diagonal line that extends to the right and downward from the wet bulb scale. A wet bulb plot is shown by the heavy line in figure 11. It is not necessary to extend the wet bulb line past its intersection with a previously plotted dry bulb line.

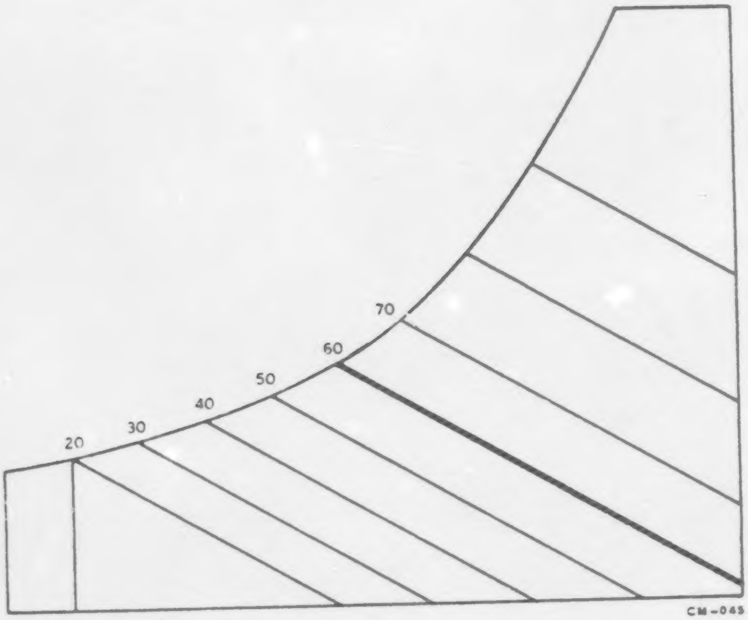


Figure 11. Wet Bulb Line

Relative Humidity (% RH)

Relative humidity is the ratio of the amount of moisture in the air compared to what the air could hold at the same temperature.

It is a percentage expression of the grains of moisture contained in the air. Relative humidity is read on or between the curved lines on the psychrometric chart. These lines are valued from 0-100 percent. The saturation curve is the 100 percent RH line. Relative humidity is read at the point of intersection of the dry bulb and wet bulb lines, as shown in figure 12.

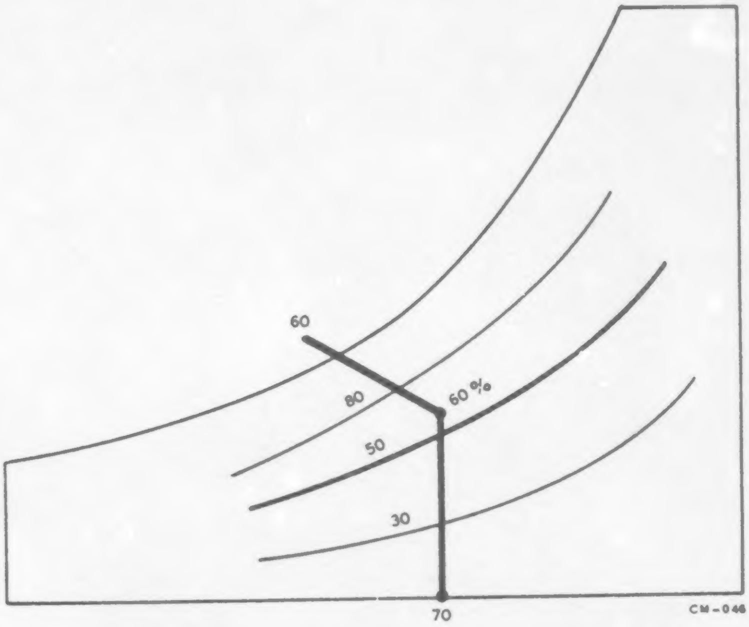


Figure 12. % Relative Humidity

Dewpoint (DP)

Dewpoint or saturation temperature, both terms mean the same. Dewpoint or saturation temperature is the temperature that allows moisture to condense on a surface. This is exemplified by the droplets of moisture, called dew, found on the grass in the warmer months, or by the frozen dew (frost) in the winter months. Windows or containers that sweat have a difference of temperature on the sides of their surfaces and are examples of dewpoint temperature being reached. Dewpoint is plotted on the horizontal line of the psychrometric chart that extends from the point of %RH to the saturation curve and the value is read at the point of intersection with the saturation curve, see figure 13.

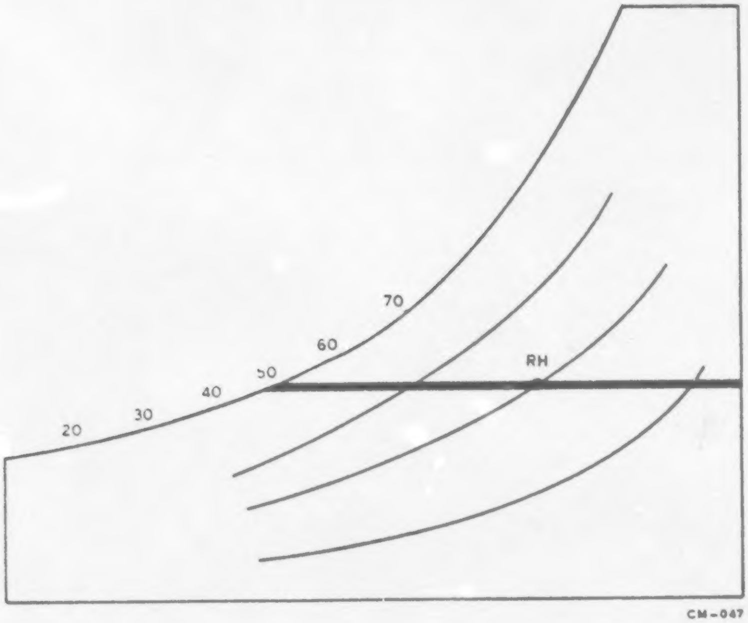


Figure 13. Dewpoint Line

Heat Content or Enthalpy

Both terms mean the same. Heat content is the measure of the Btus contained in one pound of dry air. Heat content is plotted by extending the wet bulb line through the saturation curve to the heat content or enthalpy scale located to the left of the saturation scale. Read the Btu value at the point the extended wet bulb line intersects the heat content scale as shown in figure 14.

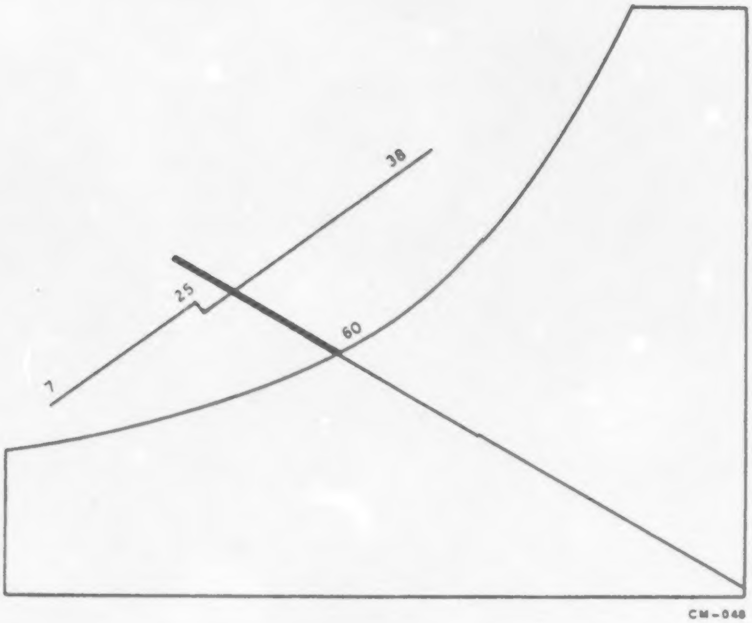


Figure 14. Heat Content Line

Grains of Moisture (GM)

Grains of moisture or specific humidity--both terms mean the same. Grains of moisture or specific humidity is the unit of measurement expressing the actual amount of moisture contained in one pound of dry air. A relative humidity plot is needed to find Sp. Hum. A grain of moisture is about the same as a drop of water. A pound of water (about 1 pint) contains 7,000 grains. To plot grains of moisture contained per pound of air, draw a horizontal line from the point of % RH to the grains of moisture scale and read the intersecting value on the chart, see figure 15.

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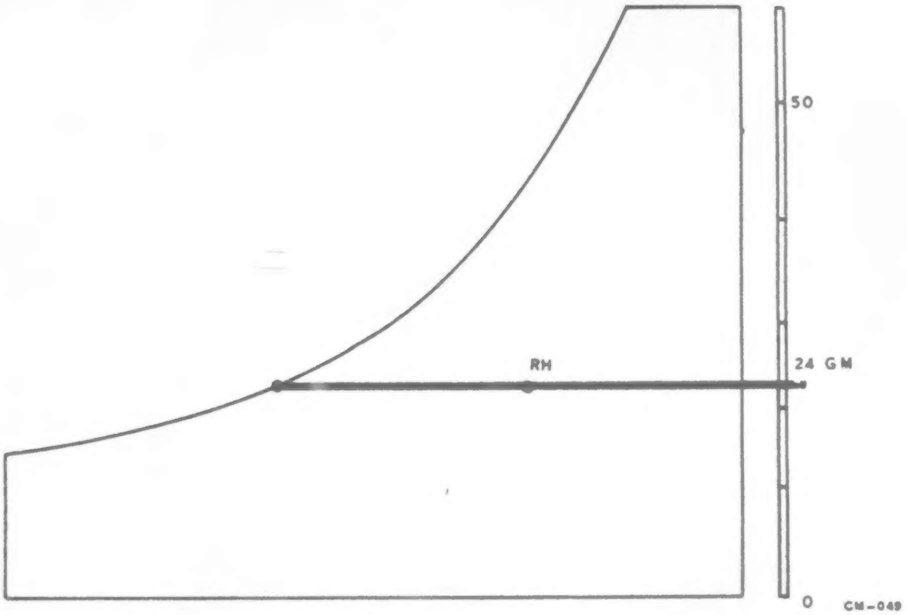

Figure 15. Grains of Moisture

Pounds of Moisture

Pounds of moisture per pound of dry air is the weight of the grains of moisture contained in one pound of dry air. It is determined by drawing a horizontal line from the grains of moisture plot to the pounds of moisture scale and reading the corresponding value at the point of intersection with the scale, see figure 16.

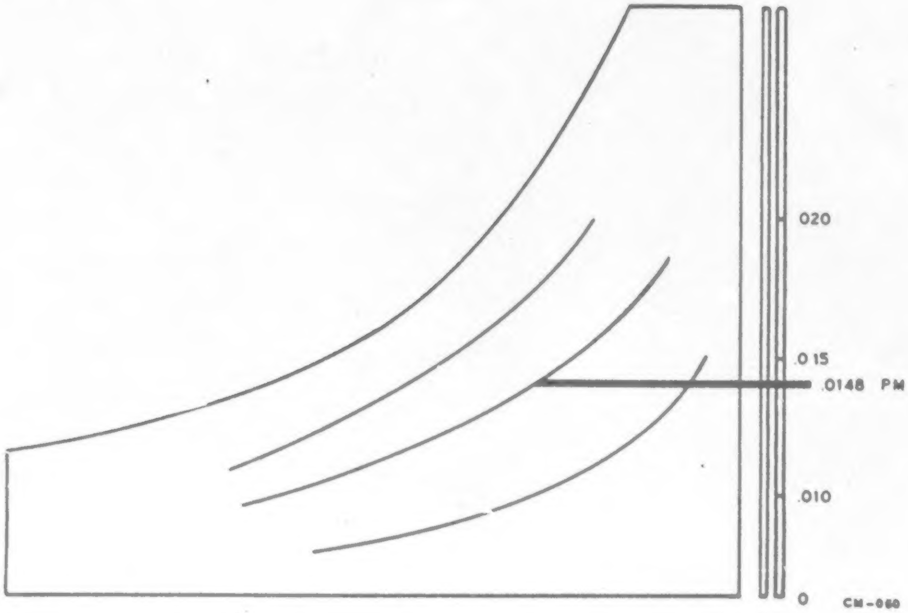

Figure 16. Pounds of Moisture Line

Specific Volume (SV)

Specific volume is the number of cubic feet of air required to weigh one pound. The specific volume lines appear as diagonal-parallel lines extending from the saturation curve to the dry bulb scale. There are five of these lines and they have a corresponding value of 12.5 cu ft thru 14.5 cu ft reading from left to right, see figure 17. To plot specific volume, draw a line parallel to the established specific volume lines from the point of % RH to the dry bulb scale.

To read specific volume plots, start with the specific volume line to the left of the new plot. For every degree Fahrenheit graduation on the dry bulb scale, add .025 until you reach the new line that you drew. Each group of four graduations will raise the volume .5 or to the next established line of the chart, see figure 18.

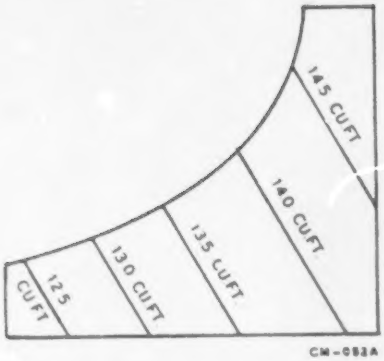

Figure 17. Specific Volume Lines

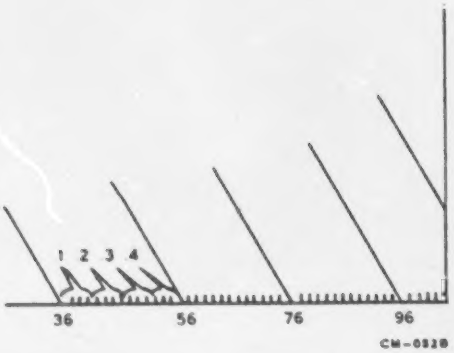

Figure 18. Specific Volume Scale

Standard Air

The conditions of standard air are 70° (DB) at sea level atmospheric pressure (14. 7 psia). One pound of standard air occupies 13. 34 cu ft of space. One cubic foot of standard air weighs . 075 lbs. Therefore, SD of standard air is . 075 lbs/ cu ft at sea level.

This standard is used as a guideline by the manufacturers of coils, fans, and other air-conditioning equipment. Practically all substances vary in volume as temperature changes. Figure 19 illustrates the properties of standard air.

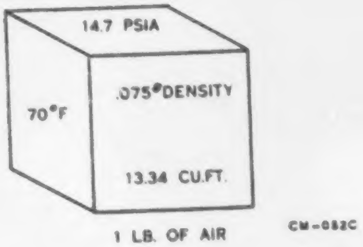

Figure 19. Standard Air Sample

Psychrometric Plots

At this point, we have defined the lines and the scales that we will use on the psychrometric chart. Figure 20 shows a composite of the lines discussed and the relationship of the various lines and scales to each other. This figure shows only a single plot, but psychrometric analysis involves two to four plots to compare all of the temperatures and properties of the air involved.

An analysis of the air in the various parts of an air-conditioning system is required when the system is put into use. Analysis is also required whenever desired conditions in the controlled space are not maintained. The analysis from each part of the system must be compared to determine how well conditioned space needs are being met and the adjustments required to provide the desired conditions.

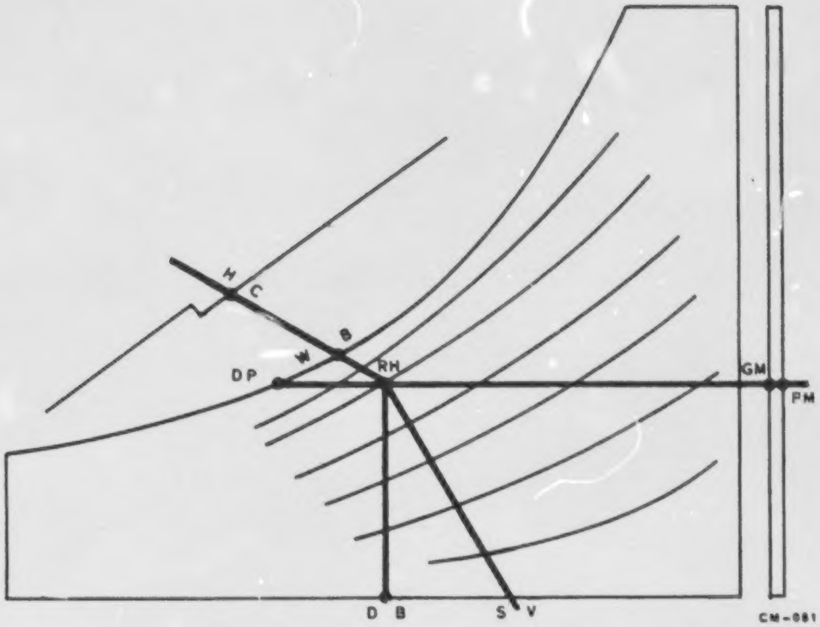

Figure 20. Psychrometric Plot

Several kinds of air are found in an air-conditioning system. As air travels throughout the system, it is given specific names to indicate the part of the system involved. We will start with Outside Air (OA). This is air brought into the system from outdoors by ducts and plenums. Air that is cooled to the desired degree and furnished to the controlled space is Supply Air (SA). As the air is recirculated into the return duct, it becomes Return Air (RA). If air is to be exhausted to offset OA brought in, the exhausted air is labeled Exhaust Air (EA). When air types are mixed in a mixing plenum, the mixture is called Mixed Air (MA).

A psychrometric plot can be made for each kind of air. Whenever the system must be checked for performance, a psychrometric plot should be made on at least two kinds of air. A comparison of these plots shows the system adjustments needed to provide the desired conditions.

PURPOSE OF LOAD ESTIMATING

The heat load of a building is directly affected by the outside conditions and the inside conditions to be modified and the extent of this modification. The greater the difference between the inside and outside design conditions the greater the heat load will be. Therefore, all comprehensive load estimates are based on the design conditions of the building and the "outdoor design condition" (design temperature standard) for the locality for which the application is being estimated. Pertinent outside design conditions include the sun angle, prevailing winds, and the psychrometric conditions of the ambient air. The inside design conditions are determined by the building usage or application. The overall heat load is a result of the design conditions, building construction, and internal heat sources.

The purpose of load estimating is to determine the amount of heat that must be removed from the conditioned space to obtain the required or desired inside design conditions. Load estimating is often referred to as "LOAD GUESTIMATING" which tends to make you think that a load estimate is not of much value. A comprehensive load estimate is much more than a guess. It is a definite requirement if the conditioning apparatus is expected to handle the heat load effectively and efficiently at the design conditions. The "RULE OF THUMB" approach to load estimating leaves much to be desired in several respects. The usual method, which is based on the floor area of the space to be conditioned, does not consider heat gain from excessive window area, heavy traffic into and out of the building, unusual internal heat sources, or even a simple thing like the effect of the building color (outside). Humidity of the conditioned space, which is of great importance to human comfort and proper operation of many types of intricate equipment, is not even remotely considered by the floor area method of load estimating. Again, the purpose of the load estimate is to determine the amount of heat that must be removed from a space to obtain the proper temperature and humidity conditions in the space. The load estimate also provides the information necessary to select the operating conditions that allow enough operating time for good dehumidification of the conditioned space.

SOURCES OF HEAT GAIN

Heat is gained into the conditioned space either as load from an internal source or as load from an external source, or both. Therefore, heat gains can be termed as "External Heat Gains" or "Internal Heat Gains" depending on where the heat originates. The origin of the heat governs the methods by which the heat gets into the conditioned space. This heat will be either sensible or latent, depending on its origin and method of transfer into the space. For instance, both latent and sensible heat may originate from the same external source. However, one type of heat is convected into the conditioned space while the other is either conducted or convected into the space.

Solar

The sun is the main source of external heat gains. The heat from the sun causes heat increases in the conditioned space either directly or indirectly. The rays from the sun heat the conditioned space directly if they strike the floor or interior walls of the conditioned space through a window or other opening in the building structure. "Solar" or "Radiant" heat, as it is often called, loads the cooling system with heat without a time lag. The sun's rays which strike the exterior walls of the building cannot penetrate the walls directly. The result is an appreciable time lag as the heat is being conducted through the walls into the conditioned space.

External Air

The temperature of the outside air, if it is above the inside design temperature, is also a source of heat load to the conditioned space. The heat from the outside air is conducted through the walls and any glass. The heat flow through the glass has a time lag similar to that of the rest of the wall. Remember, solar rays through glass do not have a time lag like conduction heat. Therefore, the heat load from the "solar effect" is faster than conducted heat loads. The psychrometric conditions of the outside air also contribute to the heat load if the air enters the building directly. Ventilation and/or "infiltration" are the methods by which the air gets directly into the conditioned space. "Ventilation" or "infiltration" affect the building heat load with little or no time lag. Again, the time lag effects are important since they determine the time at which the peak heat loads occur.

Internal Sources

People, animals, and mechanical things like lighting, household appliances, and motors are some of the heat loads that originate within a building. Moisture that is evaporated directly into the conditioned space is an important source of heat. The moisture can be given off by occupants or mechanical devices within the building. Around your home, the shower is a prime source of moisture, and therefore, a latent heat load. Gas flames release about 50 percent of their heat as water vapor which becomes latent heat load.

TYPES OF HEAT

The total heat that the cooling apparatus must handle is of two types. The types are sensible and latent. Sensible heat is the heat that changes the temperature of the air without affecting its absolute humidity. Absolute humidity is the actual moisture content of the air. Latent heat is that given up by condensation of the water vapor in the air as it passes through the cooling apparatus. Latent heat is also defined as heat removed by condensation without affecting the air temperature. For instance, when high latent loads are brought to the cooling apparatus, the moisture removal process reduces the sensible heat removing capacity of the apparatus. Latent heat is not heat load unless moisture is actually being removed. The dewpoint of the conditioned space must be lower than that of the outside air for moisture gain to the space. The apparatus dewpoint must be lower than the inside space dewpoint to remove latent heat from the total space heat load.

HOW HEAT ENTERS THE SPACE

For heat to enter the conditioned space, the space must be cooler than the heat source. Heat always flows from hot to cold. The sun has already been mentioned as a primary source of heat. It heats the external surfaces of a building and is conducted inside through the structure. The sun's rays also cause direct heat through any windows. The rays from the sun strike a surface heating it, and the heat is then radiated to the conditioned space. Solar heat does not have the time lag that is associated with the heat conducted through the walls; therefore, "solar heat gain" precedes "transmission heat gain." (Heat gain through the walls is often referred to as "transmission heat gain.")

HEAT CONDUCTION. Heat that flows through a solid material when a temperature difference exists between the opposite sides is termed "Conducted Heat."

Heat enters the conditioned space through the walls of a structure by conduction. The outer wall surfaces are heated by solar radiation and ambient air temperature. They then conduct the heat toward the interior wall surfaces, which is retarded only by the "thermal resistance" of the structure and its insulation. External heat may require hours before it reaches the interior space.

HEAT CONVECTION. Heat that is carried in a medium such as air or water from one point to another point is termed "convected heat." An example of convected heat is that carried by air to the cooling apparatus.

Heat also enters the conditioned space through cracks or openings in the structure. This heat is carried by convection and is known as "infiltration heat gain." Heated outside air mechanically introduced into a building for ventilation purposes is referred to as the "ventilation heat load." It is common where buildings have a number of human occupants or require positive inside pressure. Pressure ventilation reduces the infiltration of heat-laden air.

During warm weather, ventilation and infiltration air is usually at a higher temperature and moisture level than that of the interior air. Therefore, they add both latent and sensible heat load to the conditioned space. The sensible heat gain depends on the temperature difference (TD) between the mixing airs, while the latent heat gain depends on the grains of moisture difference between the mixing airs.

The heat gets into the space by various means. However, removal is accomplished by the convection process. An example of what occurs is the normal air-conditioning process. The heat within the conditioned space is the result of the heat gains from conduction, convection, or radiation. The heat in the conditioned space is transferred by convection, using forced air circulating equipment to the cooling apparatus. The term "FORCED CONVECTION" is common in air conditioning as most systems rely on positive air circulation.

HEAT RADIATION. Heat that causes a surface to warm because of rays striking it is termed "radiant heat."

Heat can be radiated to the space from internal or external sources, or from both sources. The external source of radiant heat (solar) is the major source of radiant heat load. It comes in through the windows or glass doors of a building. Radiant heat depends on a direct path for the rays to strike the interior of the space to add heat. We can take advantage of this characteristics of radiant heat and shade the windows from the direct sunlight and diffusion light rays (cloudy light) to reduce the heat gain. Radiant heat may also be given off by mechanism within the building. These sources are not nearly as important as the sun.

Heat Flow Ratings

Building and insulating materials are rated in terms of their characteristics. You must consider these characteristics when selecting the materials to be used or when determining the rate of heat transmission of a structure. Materials with a low rate of heat transmission should be used whenever possible. The normal materials used for construction do not retard the flow of heat very well when compared to insulation materials. Therefore, it makes good sense to insulate both old and new buildings. It is especially important when air conditioning is installed. Larger equipment and higher operating costs are the penalties for not having adequate insulation.

The heat flow ratings of a structure are the ratings of the individual materials or of the combination of materials used. Each material has a different rating. Also, ratings vary for different thicknesses of a material. The ratings, based on a 1" thickness, compare the insulating values for each variety of construction and insulation material. Ratings for actual thicknesses of typical construction (common building construction) rate the heat flow through that type of wall. This method provides the actual heat flow through the wall per sq ft. Opposition to heat flow is "thermal resistance." Thermal resistance is the reciprocal of heat flow.

Rating Factors

K-factor, C-factor, and U-factor are ratings of the heat flow value in Btus of heat. The R-factor is a rating of the thermal resistance to heat flow and is the factor which governs the heat flow at the specific conditions. The R-factor is derived from the K, C, or U-factors by dividing these factors into the number 1.

K-FACTOR (CONDUCTIVITY). This factor rates homogeneous materials of one-inch thickness and one sq ft of surface area. A homogeneous material is one of uniform composition and density throughout. In other words, it is a solid structure (such as a wooden plank or concrete slab. "Conductivity" is defined as "the amount of heat in Btus flowing through one inch of homogeneous material in one hour when the area is one sq ft and the temperature difference between the faces of the material is one degree F." The actual rating is read as "Btus per hour per sq ft and a one degree F temperature difference."

C-FACTOR (CONDUCTANCE). This factor rates nonhomogeneous materials at the total thickness for one sq ft of surface area. A nonhomogeneous material is a building material that is not solid but is hollow in construction such as concrete blocks, hollow tile blocks, or glass blocks. "Conductance" is defined as "the amount of heat in Btus flowing through a nonhomogeneous material in one hour when the surface area is one sq ft and the temperature difference between the faces is one degree F."

NOTE: The temperature difference is the surface temperatures at the faces of the materials being rated. The next factor to be discussed (U-factor) specifies the TD as between the air temperatures on each side of the material.

U-FACTOR (OVERALL HEAT TRANSFER COEFFICIENT). This factor rates homogeneous, nonhomogeneous, and combinations of building materials based on one sq ft surface area at different thicknesses. The U-factor rating includes the effect of air films on the surfaces of the materials in respect to heat flow through the air films. U-factor can be defined as the heat flow in Btus flowing through one sq ft of material in one hour when the temperature difference is one degree F between the air on the two sides of the wall or roof. As can be seen, the U-factor rating is the actual construction of the walls. Sometimes the U-factor is put into rating tables where it includes the temperature difference. (Already figured for you.)

R-FACTOR (THERMAL RESISTANCE). This factor rates the opposition to heat flow and is the reciprocal of a heat flow rating such as K, C, or U-factor. Because of the nature of the R-factor, it will be used in a different manner than the heat flow ratings. The cooling application dictates the allowable heat flow rate into the space, in respect to the equipment economics, at the design conditions of the space and the outdoor design conditions. An insulation with a thermal resistance that will limit the heat flow into the conditioned space will then be selected to match the heat flow to the assumed equipment size. The assumed cooling equipment size may be based on typical applications in the area or on an assumed thermal resistance value (used to calculate the load). The R-factor of the insulation material selected and applied to the job assures that the heat flow into the building, at the design conditions, is equal to the equipment capacity already selected.

Related Heat Flow Formulas

As previously discussed, there are different types of heat, heat loads, and methods of heat getting into the conditioned space. There are formulas that are appropriate for the different types of heat, heat loads, and methods of heat transfer. With the previously discussed heat flow rating for building materials and/or insulation, the heat flow into the conditioned space can be computed using the ratings and the appropriate formulas. The other types and methods of heat gain will use different formulas and ratings.

SENSIBLE HEAT FORMULAS. Usually, heat flow through a wall or ceiling/roof will be entirely sensible heat. In order to compute the sensible heat flow into the building, the term "SPECIFIC HEAT" must be understood. If you will recall, the "SPECIFIC HEAT" of a substance is the amount of heat that is added or removed that will change the temperature of one pound of that substance one degree F. For instance, the specific heat of air is .24 Btu per pound at 55° F DB. Therefore .24 Btu, added or removed, will change the temperature of one pound of air one degree F. The term "SPECIFIC HEAT" is dealing with sensible heat only. Latent heat formulas will be discussed later. Most of the building heat will be sensible heat, therefore, the formulas usually include the specific heat of the air. The formula used depends on the method of heat flow. For instance, to figure the heat flowing through a wall, the following formulas can be used:

HEAT (Btu) + A X U X TD

A = surface area of the wall in sq ft

U = U-factor; the amount of heat through one sq ft of the wall with one degree F. TD between the air temperatures on both sides of the wall.

TD = actual temperature difference

NOTE: The "U" used in the above formula is for one degree F TD. You may find a "U" rating that includes the TD. If the TD is included, the formula will be:

HEAT (Btu) + AREA X U

The heat brought in with the fresh air ventilation load is usually both sensible and latent heat, but is mostly sensible. To compute the sensible heat being convected into the conditioned space, the amount of air, temperature difference, and an air constant, is required. The air constant is 1.08. The 1.08 is the sensible heat absorbing or releasing capacity of the air per hour at a one degree F temperature difference. The formula is as follows:

HEAT = CFM X TD X 1.08

NOTE: The 1.08 is derived from the specific heat of air.

$$1.08 = .244 \text{ X } \frac{60}{13.34}$$

.244 - specific heat of air

60 - minutes per hour

13.34 - specific volume (cu ft/pound)

The formula discussed above will compute the heat load due to ventilation (sensible heat only).

LATENT HEAT FORMULA. Latent heat enters into a building by infiltration and/or ventilation, or originates within the conditioned space. To compute the latent heat brought in through the ventilation system, we must determine the cfm of ventilation air, compute the grains of moisture difference between the inside and outside design conditions, and then apply an air constant dealing with latent heat. The air constant is .68. The following formula will compute the latent heat brought in by ventilation:

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HEAT (latent) = CFM X Gr. MOIS. DIFF. X .68

CFM = cubic feet per minute

GR. MOIS. DIFF. = The difference in moisture content between inside and outside design conditions.

.68 = air constant. The .68 is the latent heat absorbing or releasing capacity of air per hour at one gr. of mois. diff.

NOTE: The .68 is derived from the following relationship:

$$.68 = \frac{60}{13.34} \times \frac{1076}{7000}$$

60 - Min per hour

13.34 - specific volume (cu ft/lb)

1076 - Average heat removal required to condense one pound of water vapor from the room air.

7000 - Grains of moisture to equal one pound of water.

Latent heat gain that originates from within the space is usually given in a table as an actual value in Btus. These values are totaled to determine the internal latent heat gain.

LOAD ESTIMATING CONSIDERATIONS

There are many things that must be considered in a load estimate. One of the more important considerations is the survey of the job to be estimated. The survey will tell you how much area must be cooled, how much window area must be considered, how much heat producing equipment will be used in the conditioned space, how many people will usually occupy the conditioned space, and what type of usage the building will receive. The usage of the building will often dictate what the inside design conditions will or should be. The location of the building, building orientation, and operational hours of the building are also important aspects of load estimating and are included in the survey.

Procedures

The survey must be completed before the estimate can be figured because many of the heat load computations depend on the information from survey. The different types of heat loads will then be figured individually and then totaled to obtain the overall heat load.

SOLAR HEAT GAIN. The solar heat gain is dependent on the building location, orientation to the sun and the time of the year. The time of the year and building location determine the angle at which the sunrays will strike the building walls and windows. Angles less than 90° will not have much surface heating effect as a perpendicular angle. The walls and windows are influenced by the sunrays as a result of the building orientation in respect to the sunrays. The walls, not being hit by the sunrays directly, will be considered to be shaded and will use a separate heat flow factor. The surface area of the exposed windows multiplied by the appropriate heat flow factor, for each wall direction, will indicate the solar heat effect of the building.

NOTE: Heat is also conducted through the glass of the windows due to temperature difference. Often, this conducted heat through windows is neglected, but can be figured in as wall heat gain on some load estimate forms.

WALL HEAT GAIN. Building location, orientation, and the time of the year, influence the wall heat gain in much the same manner as with the solar heat gain. The heat flow factor used for walls depends on whether the wall is in the sun or shaded. The walls in the sun will conduct more heat for a given temperature difference between the air on both sides. The difference in the shaded and sunlit factors should adjust the heat flow values to account for the sunlit walls. Find the surface area of the walls, excluding the window areas, multiplied by the appropriate factor, sunlit or shaded, and then multiplied by the design temperature difference will indicate the heat flow through the individual walls of the building. The heat flow through all the walls are totaled to yield the overall wall heat gain.

NOTE: The method used here does not include the window heat gain though design temperature difference; some load estimate procedures do consider the window gain as part of the wall heat gain.

VENTILATION HEAT GAIN. Ventilation heat gain can be either sensible, latent, or both. The volume of ventilation air depends on the number of occupants using the building, and the activities in the building. The volume for each person can be obtained from reference tables, for each person, and then multiplied by the number of occupants, to get the total cfm required. The sensible heat gain depends on the design temperature differences, required cfm, and the appropriate air constant. The latent heat gain depends on the design grains of moisture difference, cfm requirement, and the appropriate air constant for moisture change.

INTERIOR HEAT GAINS. Interior heat gains are of two general kinds. First; the occupants. The heat given off by people will be both sensible and latent. The percentage of sensible and latent depends on the degree of activity. The higher the rate of activity, the higher the latent heat released by the people. The second, general kind of interior heat gain is in the equipment category. The types of equipment which must be considered are; lights, motors, and appliances. The time of day when the lighting is in operation is very important to a heat estimate. The operating time period of electric motors is also important. The time at which the peak heat load from the lights and/or motors occur may or may not be at the same time as the other load peaks. Operation duration of appliances is also important to the hourly heat load from the interior (conditioned space). These will affect the actual peak load of the day.

To figure the actual heat load of each type of internal heat gain, the load for the different types of interior heat gain must be considered separately and then totaled. The load from the occupants in the space depends on the number of persons and the Btu factor or rating for the people's degree of activity and physical size and sex. The rating will often be given in both sensible and latent heat values for the given conditions, but may also be rated according to an adjusted average for several sizes of people. The number of people, multiplied by the heat release factors, will indicate the amount of heat that is given off by the people in the building at the inside design conditions. Latent and sensible heat gains should be computed separately and then totaled into the correct columns.

To compute the hourly heat load from lights and motors, the number of lights and total horespower must be multiplied by a specific factor. One for each kind of load.

To compute the hourly heat load from appliances, find the hourly heat value listed in the tables and multiply it by the number of the specific appliances. The heat values are then added into the correct column, either latent or sensible, so they will be included in the overall heat load total. The subtotal column allows the heat load to be figured for each type of "Heat Gain" and then totaled up to the overall load. The latent and sensible columns allow the overall heat load to be broken down into latent and sensible heat loads. The ratio of sensible heat to the overall heat load will be used later to determine the best chilled supply air condition to satisfy the heat loads in the proper proportions. The overall heat load will be used to select the proper tonnage for the cooling apparatus.

PSYCHROMETRIC PROBLEMS AND AIR MIXTURES

In studying the psychrometric chart, the conditions are plotted for the air passing through a system. To graphically illustrate the conditions of the air at given points, we must identify a few more terms that will apply in this study. Some of the terms include the following:

- Grains of Moisture Removed
- Pounds of Moisture Removed
- Total Btu Removed
- Sensible Btu Removed
- Latent Heat Btu Removed
- Coil Slope
- Room Slope
- Apparatus Dewpoint
- Mixed Air Plots

NOTE: In psychrometrics, all values on the chart are per pound of dry air.

Procedures

GRAINS OF MOISTURE REMOVED. This quantity is found by subtracting the GM of the smaller plot considered from the GM of the larger plot being considered.

For example, if the returned air (RA) plot contained 98 GM and the supply air (SA) plot contained 77 GM, subtract 77 from 98 and the difference would be 21 GM removed.

POUNDS OF MOISTURE REMOVED. This amount would be determined by the same procedure. If the outside air (OA) plot contained .014 lb and the RA plot contained .0076 lb, subtract .0076 from .014 and the difference would be .0064 pounds of moisture that were removed.

HEAT CONTENT REMOVED. This can be found by subtracting the heat content (HC) of the smaller plot from the HC of the larger plot and the difference would be the Btu heat content difference. Earlier in this course you learned that total heat is sensible plus latent heat. Therefore, when necessary, the total heat removed can be separated into specific amounts of sensible heat and latent heat.

Sensible heat changes the temperature of a substance but not its state. Latent heat changes the state of a substance but not its temperature. When applied to water, sensible heat changes the temperature of the water but it remains water. Latent heat changes water at 212°F to steam at 212°F, thereby changing its state from a liquid to a vapor but with no change of temperature. Sensible heat is measurable with a thermometer; latent heat is not. In air-conditioning work, latent heat is involved only by the addition or removal of moisture in the air. The psychrometric chart is the only tool you have to calculate latent heat.

The total heat removed by an air-conditioning unit is simple to calculate on a psychrometric chart. You begin by determining both the dry bulb and wet bulb temperature of the supply air and the return air. Plot both dry bulb temperatures on the chart, as shown in figure 21. Then, plot the wet bulb temperatures and extend their lines through the heat content scale. The total heat removed is the difference between the Btu readings taken at the intersection points of the WB lines with the heat content scale. For example, as shown in figure 21, 34 minus 15 equals 19 Btu of heat removed.

When necessary, you can determine how much of the heat removed is sensible heat and how much is latent heat. To determine sensible heat, draw a horizontal line from the % RH point for SA until it intersects with the RA line as shown in figure 21. From this point of intersection, draw a line parallel to the WB lines to the heat content scale. The difference in the Btu readings at this point and the SA wet bulb line is sensible heat. As shown in figure 21, 26 minus 15 equals 11 Btu of sensible heat. Latent heat is the total heat minus sensible heat. Following through on figure 21 this is 19 minus 11, giving a latent heat content of 8 Btu.

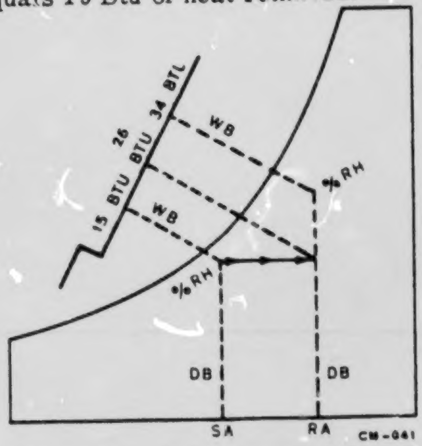

Figure 21. Heat Removal Plots

COIL SLOPE. This is the amount of Btu removed from the air entering and leaving a coil. To graphically illustrate coil slope, you must join the % RH points of the temperature entering (TE) and the temperature leaving (TL) with a straight line, and read the answer on the HC scale by subtracting the HC of TL from the HC of TE, see figure 22.

ROOM SLOPE. This is the amount of Btu that are picked up in a room from the time air enters as supply air and leaves as return air. Plotting procedures are the same as for coil slope; join the % RHof TE and the TL with a straight line and read the answer on the HC scale by subtracting the HC of SA from the HC of RA and recording the difference, see figure 22.

APPARATUS DEWPOINT. This is the effective surface temperature of the cooling coil. The term apparatus dewpoint refers to the cooling coil of an air-conditioning system. To plot apparatus dewpoint, join the % RH of TE of the coil and the TL of the coil and extend the line straight to the saturation curve and read the temperature at the point of intersection. Most manufacturers design their cooling coils to be maintained at 40°F. This prevents freezeup of the coil.

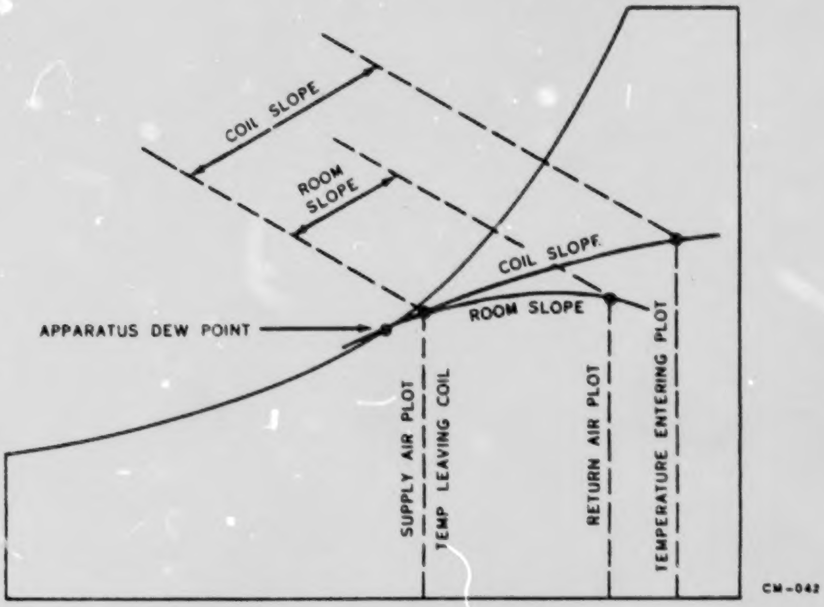

Figure 22. Coil Slope, Room Slope, and Apparatus Dewpoint

MIXED AIR PLOTS. Mixed air is the process of combining any two airflows to be introduced into some part of the system. Normally this mixture would be between RA and OA (but can include others). After being mixed, it is passed over a coil for conditioning prior to entering the controlled space.

Mixed air will appear on the psychrometric chart between the two conditions being mixed depending on the ratio of the air being mixed. For example, if the air mixture was based on a 50 percent mixture, the plot would appear halfway between the dry bulb lines of the two plots, see figure 23.

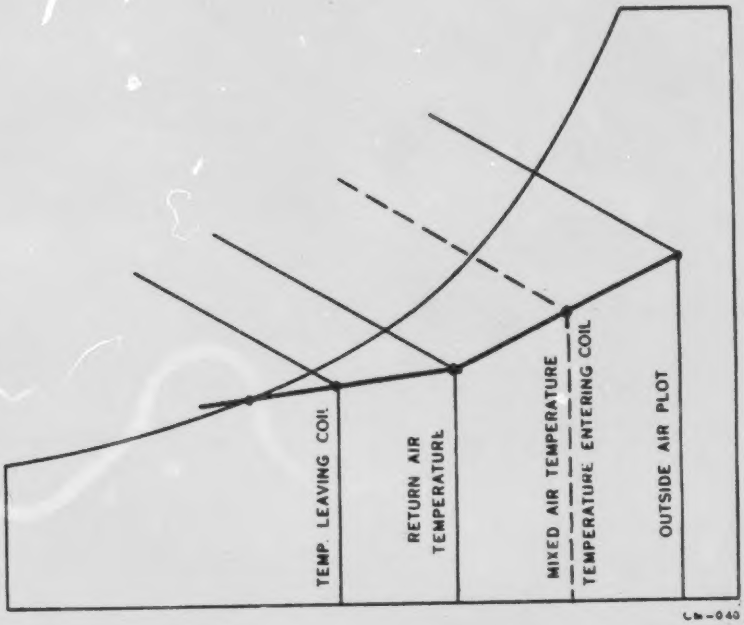

Figure 23. Mixed Air Plot

To plot mixed air, use the following steps:

1. Draw a diagonal line to connect the % RH points of OA and RA (this will give you the % RH of MA after the DB of MA is established).

2. Find the percent of outside air in the mixed air. If 2,000 cfm outside air is added to 4,000 cfm RA, the ratio would be:

$$\frac{2000}{2000 + 4000} = \frac{2000}{6000} = \frac{2}{6} = \frac{1}{3} = 33\ 1/3 \text{ percent}$$

3. To find the dry bulb temperature difference, subtract the RA DB temperature from the OA DB temperature.

4. To find the change in temperature. Multiply the TD from step 3 by the percentage figure from step 2 for degrees of change.

5. To find the MA DB temperature, add the value of step 4 to the RA DB temperature.

6. Finish the MA plot by drawing the DB line to the diagonal line established in step 1. and finish the plot.

Determining Supply Air Conditions and Volumes for Heat Load Demand

One very important factor in determining supply air volume required is the condition of the air being supplied. To thoroughly understand the effect of the air's condition, some basic rules must be reviewed and understood.

1. The ability of the supply air to absorb sensible heat depends on the temperature difference.

2. The ability of the supply air to absorb moisture depends on the dryness of the air supplied. Since the air always contains some moisture, the absorbing ability varies with the humidity of the air supplied.

3. Cold supply air, by itself, will not provide comfort if the moisture content of the supply air is too great. The resulting humidity condition in the space will be too high for comfort.

To properly condition a space for comfort, the rules above must be kept in mind. There are some accepted industry standards that are used in calculations for comfort cooling. These standards are shown below.

1. Standard Air - Air at 70°F DB and 14.7 psia (sea level) is considered the standard conditions. One cu ft of standard air weighs .075 lbs therefore 13.34 cu ft of standard air weighs one lb.

2. Density of standard air - The density of standard air is .075 lbs/cu ft.

3. Specific heat of air - The specific heat value normally used in supply air calculations is .24 Btu/lb per °F. (.244 Btu/lb/degree F is the specific heat at 55°F (db) air for design purposes.) The specific heat of air is the amount of heat required or released to change the temperature of one pound of air one degree F.

SUPPLY AIR CONDITION. The required condition of the supply air is dictated by the sensible and latent heat loads within the building to be conditioned. The ratio of the sensible load to the total load is known as the sensible heat ratio (SHR) or sensible heat factor (SHF). The supply air must remove the correct ratio of sensible and latent heat from the conditioned space. Some psychrometric charts have a SHF or SHR scale that can be used to determine a supply air condition that will provide the correct ratio of sensible and latent cooling.

Using the SHF Scale on the Chart. The SHF scale is located at the upper right corner of the chart as shown in figure 24. A reference point is located at 80°F db and 50 % RH on the chart and is used with the SHF scale. A straight line drawn between the SHF scale and the reference point will establish a reference angle on the chart as shown in figure 25. Any cooling process (coil or room slope) that parallels the reference angle will have the same SHF. That means that the sensible and latent heat will be removed in the same proportions that the heat loads exist in the conditioned spaces. Any supply air condition that falls on the cooling process line (coil or room slope) will remove heat from the conditioned space in the correct ratio.

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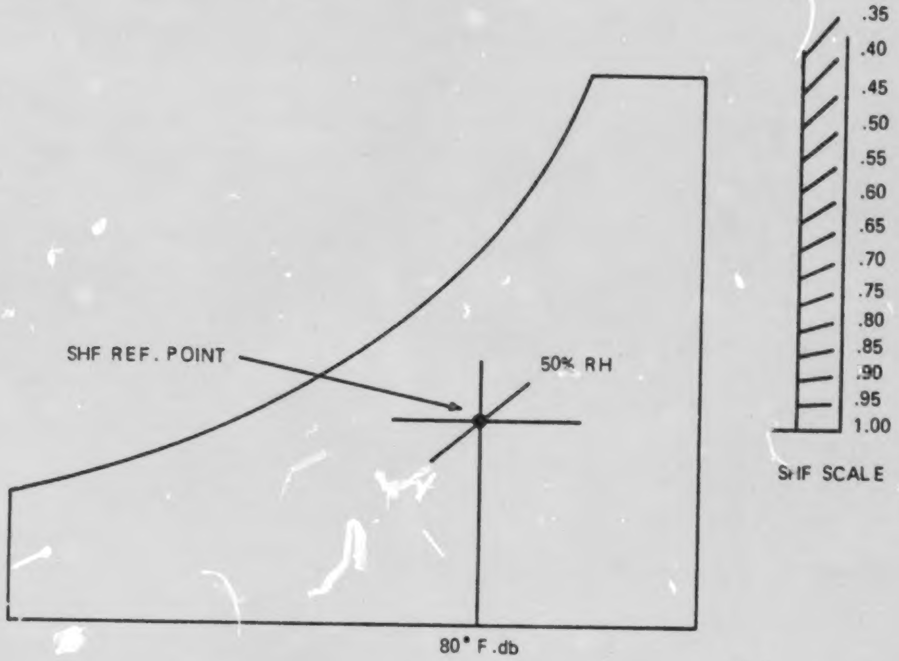
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
1.00
SHF SCALE
SHF REF. POINT
50% RH
80° F.db

Figure 24. SHF Scale and Reference Point

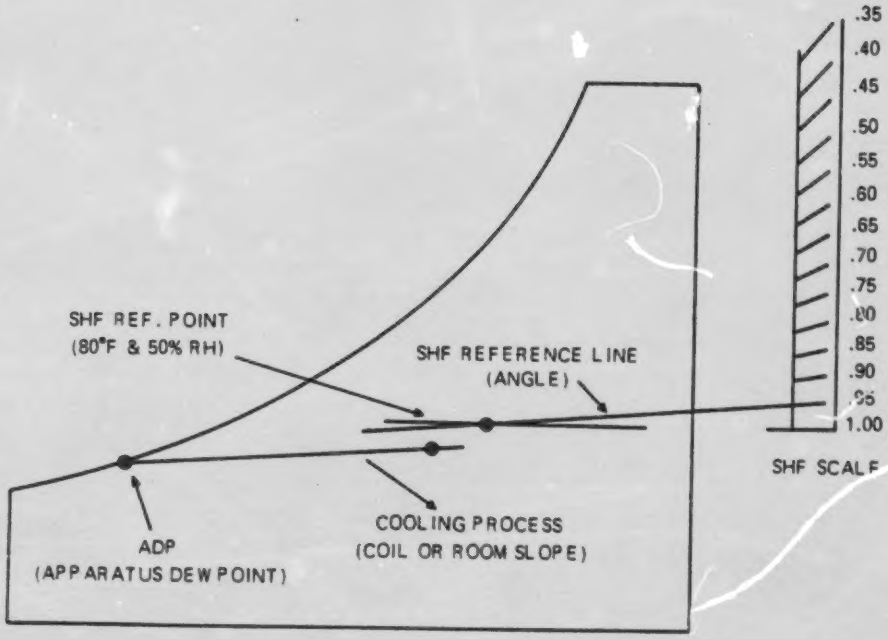
.35
.40
.45
.50
.55
.60
.65
.70
.75
.80
.85
.90
.95
1.00
SHF SCALE
SHF REF. POINT
(80°F & 50% RH)
SHF REFERENCE LINE
(ANGLE)
ADP
(APPARATUS DEW POINT)
COOLING PROCESS
(COIL OR ROOM SLOPE)

Figure 25. SHF Reference Angle and Parallel Cooling Process

Supply Air Temperature. The supply air temperature is effected by several things, but coil efficiency is most important (outside of capacity). Manufacturers try to make their coils as efficient as possible without adding excessive resistance to airflow through the fins. At higher efficiencies, the supply air will be colder, thus more dehumidification can be accomplished than with lower efficiency coils. The efficiency rating gives indications that help in selecting a cooling coil for the application.

Some of the air will flow through a coil but will not come in contact with the coil surface. This is called bypass air. The amount of air that flows through the coil, that does not contact the coil surface, depends upon the coil construction (fins per inch) and the velocity of the airflow.

The bypass factor for cooling coils is determined through tests and calculations so that the factors are known before the coil is installed. In this manner, it is possible to predict coil performance and to select the best coil for the particular application. The average bypass factor used in comfort air conditioning is usually between .10 and .30, and varies according to the combination of conditions and equipment.

The following procedure can be used to find the bypass factor of a coil:

1. Subtract the apparatus dewpoint temperature (coil temperature) from the temperature of the air leaving the coil.

2. Subtract the apparatus dewpoint temperature from the temperature of the air entering the coil.

3. Divide the answer in step 1 by the answer in step 2.

If the bypass factor is high, the following conditions must be provided to produce the required leaving air temperature at the coil·

1. More air at slower speeds (velocity).

2. Larger ducts are required for the larger air quantities.

3. Larger fans and motors to supply the larger air quantities.

If the bypass factor is low, the following conditions can be provided.

1. With a lower leaving air temperature, less air is required.

2. Less air will be required, permitting the use of smaller ducts and smaller fans and motors.

A low bypass factor may also have certain disadvantages.

1. Discomfort in small rooms due to a low supply air temperature.

2. Larger equipment may be required to compensate for the increased load provided by better air contact with the coil.

3. Insulation and vapor seal may be required because of the low temperature in the supply duct in the room.

A 90 percent efficient coil will provide dehumidified air of at least 90 % RH leaving. A relative humidity of 90 percent or higher indicates excellent performance. (Ninety percent efficiency or 90 % RH can be used to select a supply air temperature.) To determine the supply air temperature from a 90 percent efficient coil, the coil temperature (surface) must be known and the entering air temperature must also be known to establish their temperature difference. The following computations will illustrate:

ent. air. temp.	78°F
coil sur. temp.	42°F
coil efficiency	90 percent

78 - 42 = 36° TD (Maximum cooling that is possible with the given conditions of the application.)

36° X .90 = 32.4

78 - 32.4 = 45.6°F temperature of supply air from the coil

The supply air temperature from the computations above would be too low for normal comfort cooling but just right for high humidity loads. A load with a .70 SHF would require about a 50°F coil surface. Either a lower efficiency coil or a higher refrigerant temperature must be used.

The supply temperature can be figured on the psychrometric chart using a simple procedure. (Based on .70 SHF.)

Establish SHF from load estimate.

Plot SHF line on chart.

Plot cooling process on chart - extend the cooling process line on past the saturation curve of the chart.

ADP is the temperature at which the cooling process line crosses the saturation curve.

ROOM CONDITION - ADP = max. cooling possible (TD)

78°F - 50°F - 28°F TD

28°F X .90 = 25.2°F

78°F - 25.2° = 52.8°F supply air temperature

The supply air temperature just computed is based on the SHF of the heat load and the coil efficiency. A heat load with a different SHF would require a different supply air temperature. To obtain the required air temperatures, the cooling coil is selected from manufacturer's data. Sometimes the supply air temperature is selected, based on the cooling unit's normal supply air temperature, but this method doesn't consider the SHF of the load.

Sometime observe the actual comfort conditions in an air-conditioned building. You will find many cases where the conditioned spaces are cool but clammy. The most probable reason for the condition is that the SHF was not considered.

DETERMINING THE VOLUME OF SUPPLY AIR. Once the supply air condition is known, then the supply air volume needed to absorb the heat load in the conditioned space can be determined.

The following things must be known in order to determine the supply air volume.

1. Specific heat of the air.
2. Temperature difference between conditioned space and the supply air.
3. Specific density of the air. (Weight of the air per cubic foot.)
4. Btu/hr heat load of the conditioned space.

The following formula is used to obtain the cfm of supply air required.

$$\text{CFM} - \frac{\text{Btu/hr (space heat load)}}{1.08 \text{ X TD}}$$

CFM - cu ft per min

Btu/hr - heat load as obtained from the load estimate.

TD - the temperature difference

1.08 - Btu/hr factor derived from the following calculations.

Remember 13.34 cu ft of standard air weighs one pound, and one cu ft weighs only .075 lbs.

ASSUMPTION: If one cu ft of air is delivered per minute, then 60 cu ft will flow per hour. Therefore, if we have 60 cu ft per hour and each cu ft weighs .075 lbs, then .075 lbs times 60 cu ft equals pounds per hour.

Pounds per hour X specific heat (.24 Btu/lb/$^{\circ}$F) equals heat absorbing capacity of 60 cu ft of air per hour.

Remember 1.08 equals heat absorbing capacity per hour per degree.

EXAMPLE PROBLEM:

Building heat load.	38,000 Btu/hr	38,000 Btu/hr
Building design temp.	78°F	78°F
Supply air temp.	52°F	52°F
FORMULA: CFM =	$\frac{\text{Btu/hr}}{1.08 \times \text{TD}}$	$\frac{\text{Btu/hr}}{1.08 \times \text{TD}}$
CFM =	$\frac{38,000}{1.08 \times (78 - 52)}$	$\frac{38,000}{1.08 \times (78 - 58)}$
CFM =	$\frac{38,000}{1.08 \times (26)}$	$\frac{38,000}{1.08 \times (20)}$
CFM =	$\frac{38,000}{28.08}$	$\frac{38,000}{21.60}$
CFM =	1357.1	1759

The CFM required for the individual rooms can be determined also, however the heat load must be figured for each room, then the air volume requirement is computed the same as above.

DUCT SIZING. To deliver the supply air to the conditioned spaces, air passages (ducts) are connected between the cooling apparatus and the rooms. To obtain the correct airflow and quietness, the ducts must be properly sized. The physical size depends somewhat on the shape or construction.

There are two shapes of ducts normally used in air conditioning: round and rectangular. The round ducts are more efficient based on volume of air per duct perimeter distance. Therefore, less duct material is needed for the same amount of airflow. Round ducts are also constructed so they can be easily assembled on the job site. Economics and convenience are important considerations. Rectangular ducts require more duct material than round ducts for the same airflow. They are more expensive because of material and manufacturer's cost. Rectangular ducts have the advantage of fitting well in constructions where space is important such as walls and ceilings.

The materials normally found in duct construction are sheet metal, aluminum, fiberglass, and less commonly, tile and cement. Each has advantages and disadvantages. For example, sheet metal is heavier than aluminum but cost less. Aluminum and fiberglass are not as apt to corrode. Tile and cement ducts are more suitable to slab floor construction. The application often determines the type of ducts used.

The air delivered to the conditioned space must be adequate for cooling but must also remain quiet as it enters the room. The velocity of the air has a big effect on the noise level, so the velocity must be kept within the acceptable range for the applications. Once the recommended velocity has been established, then charts, and duct size calculators can be used to select the proper size duct for the required air volume. The use of a duct calculator will be shown in class.

The pressure losses in the duct may also be calculated on the duct sizers. The friction losses are important in selecting the air circulator to overcome the duct system losses. Air circulating equipment ratings are usually stated as so many CFM at a certain static pressure. The static pressure rating must be higher than the duct system losses. In addition to the friction losses in the duct, there are also losses at the supply air and return air registers and grills, cooling coils, filters, and any bends in the duct. The fan must be capable of delivering the correct volume of air through the complete air handling system against the total air handling system losses. The friction losses for the various components in a duct system can be figured from friction loss tables and charts. Once the friction losses have been computed, the fan may be selected to meet the system requirements.

AIRFLOW BALANCING. Air-conditioning mechanisms are designed to condition the air within the cooling or heating apparatus and then convey the treated air to the conditioned space in the correct amount without causing drafts or excessive noise. Duct types and sizing have been discussed in relation to the construction and correct air delivery volume. The noise level was considered when the ducts were sized but there is another factor to consider. The air velocity must be sufficient to throw the supply air out into the rooms in order to promote air movement within the space. The location of the air outlet is very important in preventing stratification of the air within the conditioned spaces. Without proper placement and sufficient air throw from the supply air diffuser, even the correct volume of supply air may not provide comfort all over the conditioned spaces. The location of the return air register has been found to be a problem in many installations where parts of a building would not cool or heat properly while the rest was conditioned as designed.

As can be seen from the above paragraph, there are several factors within the conditioned space that affect final results of the air-conditioning process. These factors can sometimes be adjusted by balancing the airflow to each room to compensate for the room's individual needs.

There are many factors within the conditioned space that effect the temperature and air distribution within the space. The supply and return air diffusers must be properly located and adjusted to cause even distribution of the air. To assure that each room receives the correct amount of air, as designed, the airflow must be adjusted to the needs of each room. The exact procedure depends on the special requirements of the conditioned space. The following procedure is only a general approach to balancing an air-conditioning system's airflow.

1. Position dampers and room diffusers to obtain maximum airflow and compare to the design air volumes.

2. Adjust dampers to obtain air volume that is closer to the required CFM.

NOTE: This step must be repeated several times because each damper adjustment will effect the other air volumes.

3. Record the CFM values after each complete round of adjustments so as to keep track of the system's reaction AND PROGRESS TOWARD THE CORRECT AIR VOLUME.

4. Continue making adjustments until the required CFM values have been obtained.

5. Adjust room diffusers to obtain good airflow within the individual spaces.

NOTE: Operate the system to check the cooling times needed for the various rooms and the temperatures of each room as the unit cycles off. The required cooling times and temperatures should be comparable for each room.

System Capacity Check Using Psychrometric Chart

From the previous study of psychrometric problems and air mixtures, you learned about cooling process lines (coil or room slopes). The coil slope represents mixed air entering the cooling coil and leaving as supply air. The room slope represents return air entering the cooling coil and leaving as supply air. Both of the slopes represent the cooling effect that is taking place in the cooling coil. The heat content of the supply air and return air is read directly from the heat content scale on the chart. The difference between the heat contents of supply air and the return air (or mixed air) is termed as HEAT CONTENT DIFFERENT (HCD) and is read as Btus/lb of dry air.

The heat content difference from the chart represents only one pound of air. Air is usually measured in a unit of volume and is normally expressed as CUBIC FEET PER MINUTE (CFM). To apply the chart to the system air analysis, the CFM must be converted to pounds of air. Standard air weighs .075 lb/cu ft, therefore if each cubic foot of air weighs .075 lb, then the CMF multiplied by the density of standard air equals pounds of air per minute.

$$\text{CFM X SP DEN} = \text{LBS OF AIR PER MIN}$$

$$\text{CFM X .075} = \text{LBS OF AIR PER MIN}$$

Btus/min can be computed by multiplying the pounds of air per minute times the HEAT CONTENT DIFFERENCE of the air going through the coil.

$$\text{CFM X .075 X HCD} = \text{Btus PER MIN}$$

To convert the Btus PER MINUTE to tons, divide the Btus by 200 Btus/min.

$$\text{TONS} = \frac{\text{CFM X .075 X HCD}}{200(\text{Btus/min})}$$

The above formula is the complete formula for computing coil capacity using the psychrometric chart. The values for the formula come from the psychrometric chart, direct measurement of the air volume through the coil, and standard air. 200 Btus/min comes from the definition of one ton.

In the previous study material, the concepts of designing an air-conditioning system have been discussed. In those discussions, emphasis was put on the SHF, supply air condition, supply air volume, and balancing the supply airflow to assure properly conditioned spaces. Once an air-conditioning system is installed and operational, the performance of the system can be checked by the methods just discussed for capacity checks. The changes in heat content of the conditioned is a direct indication of cooling capacity of the system.

SUMMARY

Air velocity can be measured with an anemometer, manometer, or velometer. After velocity is known, it is a simple matter to determine the cfm and pounds per minute of air being changed in the space involved.

The analysis of air is a valuable tool for the specialist. Psychrometrics give him an understanding of what the mechanical cooling process must overcome to properly perform. In order to correctly determine the properties of air, the refrigeration specialist must be able to use the psychrometric chart.

The psychrometric chart also provides a means of selecting the proper air condition needed to cool the conditioned space in the best latent and sensible heat ratio. The chart is the connecting link between the load estimate and the cooling equipment.

REFERENCES

AFM 85-18, Maintenance and Operation of Refrigeration, Air-Conditioning and Evaporative Cooling and Mechanical Ventilating Systems

Textbook, Trane Air-Conditioning Manual

Textbook, Air Conditioning, Delmar

Textbook, Modern Refrigeration and Air Conditioning, Althouse, Turnquist, and Bracciano

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DIRECT EXPANSION AIR-CONDITIONING SYSTEMS

OBJECTIVES

This study guide will aid you in learning the operation, service procedures, troubleshooting, and repair of direct expansion air-conditioning systems such as window units, package air conditioners, and residential cooling and heating systems. (Split refrigeration system added to the basic forced air heating system.)

INTRODUCTION

Direct expansion type of cooling is the most common method. It means that the supply air is cooled by the finned cooling coil directly. Air conditioners such as window units, package units, and residential split systems use the direct expansion method.

WINDOW UNITS

The components and controls discussed in previous units of instruction are typical of those used in most modern window and residential air-conditioning systems. Each manufacturer has his own method of applying these various components and controls. No attempt will be made to give a detailed discussion about specific makes and models of equipment.

A window air conditioner, figure 26, can best be described as a self-contained unit. It is used either mounted in a window or through a wall. It is usually capable of circulating, cleaning, and cooling the air, and, in some instances, may also include means for ventilating and heating. Window air conditioners are primarily designed for cooling one room only with free air delivery (without ducts). They consist primarily of a compressor, condenser, evaporator, capillary tube metering device, a fan and blower motor assembly, a filter, and the necessary motor assembly, a filter, and the necessary electrical controls. A short discussion of these components is as follows.

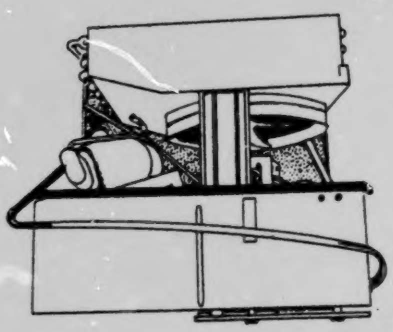

Figure 26.

Major Components

COMPRESSORS. Window units use the hermetic-style compressor and many have potential-type starting relays. However, most modern window units use a permanent split capacitor (PSC) compressor, see figure 27. A PSC compressor has two main advantages.

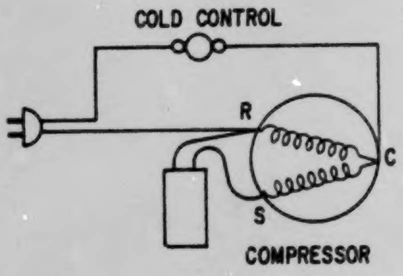

Figure 27.

1. It does not require a starting relay.
2. A small unit will produce more power because the start winding is also used for running.

CONDENSER. The condenser is usually composed of rows of copper tubing covered with aluminum fins. It is larger than the evaporator, so it can dissipate all of the heat picked up by the evaporator plus the heat of compression. The condensate water which is relatively free of scaling minerals is thrown against the condenser, thus, aiding in reducing the head pressure by making it an evaporative condenser. The water thrown against the condenser causes dirt and trash to collect on the fins. As a result, the condenser must be cleaned periodically.

EVAPORATOR. The cooling section is usually composed of rows of copper tubing covered with aluminum fins. The collected water droplets collect at the bottom of the cooling coil and are drained through a tube or trench to the back of the unit. The slinger ring will then pick up the water and throw it against the condenser where it evaporates. The evaporator is designed to lower the temperature approximately 20 degrees. If the air entering the coil is 90 degrees and the air leaving the coil is 70 degrees, the unit is said to be performing at maximum design.

CAPILLARY TUBE METERING DEVICE. This metering device operates on the principle of restriction. It operates on the pressure difference between the high side and the low side. A tube is chosen that will allow just enough liquid to pass through it to make up for the amount vaporized in the evaporator as the compressor operates. Because there is no shutoff valve, the pressures equalize during the off cycle. This equalizing of pressure permits easier starting of the compressor.

EVAPORATOR BLOWER. In order to make window units as quiet as possible, a squirrel cage blower is used to force air through the cooling coil. Squirrel cage blowers are much quieter than the blade type fans and will move a higher volume of air providing the diameter of the fans is the same. The blower is designed to move approximately 400 cfm per ton of refrigeration.

CONDENSER FAN. A fan is used to force air through the condenser. The condenser fan operates in the outside area to dissipate the unwanted heat, therefore, noise is not a major consideration. The fan blades are connected at the outer tip by a metal band which gives the blades stability, but the main purpose of this band is to pick up condensate water and sling it against the condenser. Naturally, this ring is called a slinger ring. This water aids in displacing unwanted heat through the process of evaporation adding to the efficiency of the condenser coil.

FAN MOTOR. The fan motor is specially designed, rugged, multispeed motor with a double shaft. The speed range is 850 to 1075 rpm. One end of the motor shaft drives the squirrel cage blower that forces air through the evaporator. The other end of the shaft drives the blower that forces air through the condenser coil. Most of these motors also use a small run capacitor in the circuit. The motor is subject to two main malfunctions, burnout and worn bearings. If the worn bearings aren't immediately replaced, they can be the cause of a motor burnout.

AIR FILTERS. Air filters used in window units are either throwaway or permanent in design. They must be changed or cleaned as soon as they become dirty. This should be done as often as needed. The cleanable type should be washed in warm, soapy water, allowed to drain dry, then coated with a thin coat of filter oil. The filters reduce the amount of lint and dust in the air, but their main function is to keep the evaporator coil clean. If the air conditioner is operated without the filter in place, the evaporator becomes dirty and requires cleaning with water and air pressure.

SELECTOR SWITCH. Most window units are equipped with a selector switch having five positions: OFF, LOW-COOL, HIGH-COOL, LOW-FAN, and HIGH-FAN. The selections may be made by pushing a button or turning a knob. The high-speed compressor operates at a constant speed. The fan has two speeds and will operate on either high or low. When a selector switch gives trouble, it must be replaced.

THERMOSTAT. Window units are equipped with a thermostat that cycles the compressor when the temperature reaches the set point. The thermostat usually has a fixed differential of 5 degrees and an adjustable range.

VOLTAGE SELECTOR. Some units are designed to operate on either 208v or 230v ac. Be sure the voltage selector switch is correctly positioned for the voltage being used in the circuit.

CAPACITORS. Start capacitors are usually small in size and round in shape. They are encased in bakelite, plastic, or cardboard. Run capacitors are larger and are long, often oblong in shape, or sometimes square with the case being made of metal. The larger microfarad ratings identify the start capacitors.

POWER CORD. Power cords for 115-120v units usually have three wires: white, black, and green. The green wire is the ground wire according to safety standard color codes. One end of this wire must be attached to the unit body and the other to the ground terminal of the plug. The black wire is the hot lead, and the white wire is the common lead.

POWER RECEPTACLES:

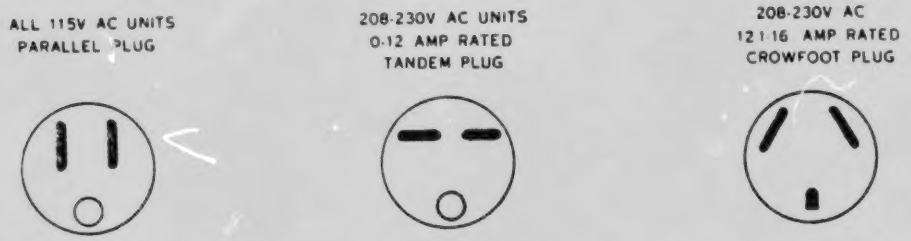

Figure 28.

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Operation

A window air conditioner has two separate and distinct air circuits (figure 29).

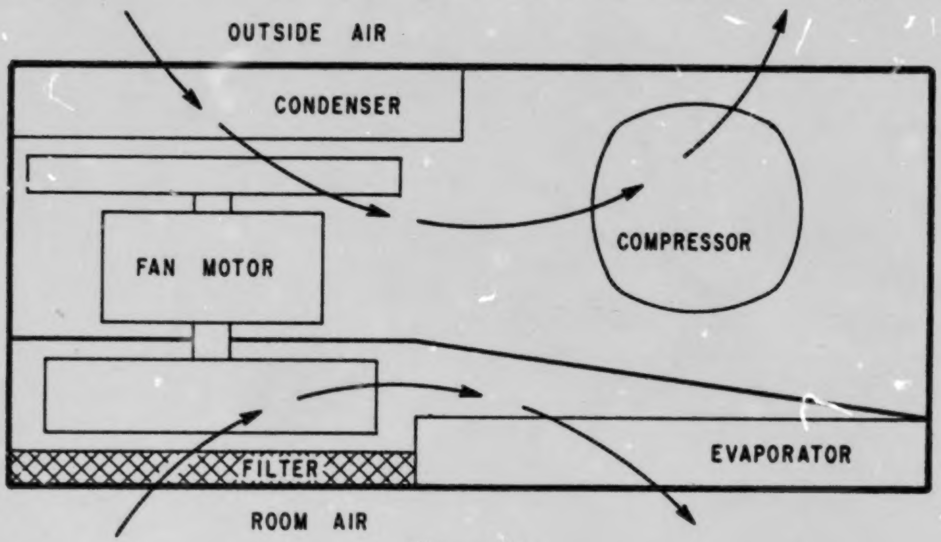

Figure 29.

1. (Cooled Room Air) Warm air from the room is drawn into the unit through the filter which removes lint, dust, and other impurities. From the filter the air passes through the evaporator where it gives up its sensible and latent heat to the liquid refrigerant changing it to a gas. Then the air goes back into the room as conditioned air.

2. (Outside Air) As the refrigerant is changed into a gas it is then pumped by the compressor to the condenser at a higher temperature than the outside air. The outside air is drawn through the condenser over the compressor and back outside carrying with it the heat removed from the condenser.

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Capacities of Window Air Conditioners

The capacities of window air conditioners range approximately from 4000 to 3,2000 Btu per hour and are often referred to as 1/2-, 1-, or 3-ton units. Capacity was originally designated in terms of compressor motor horsepower; however, this has proved to be inaccurate for measuring actual cooling capacity.

Window air conditioners should be able to operate at their rated capacity, under the following conditions which are the manufacturing standards for window air conditioners.

a. Outside air . . . . 95°F Dry Bulb and 75°F Wet Bulb temperatures

b. Inside air . . . . 80°F Dry Bulb and 67°F Wet Bulb temperatures

c. Voltage . . . . ± 10 percent of full rated voltage

Refrigerant

Most window units use R-22 refrigerant. The unit can be about one-third smaller in size. This is due to the fact that the heat of vaporization of R-22 is 69 Btu, compared to only 37 Btu for R-12.

Installation

Installation procedures will differ a little between models and manufacturers. However, if you can install one type, you can figure out how to install any of the other types Some general procedures are listed below.

- Install in the shade if possible.
- Guarantee complete ventilation for the condenser if possible.
- The back of the unit should be 1/2 to 1/4 inch lower than the front to allow proper drainage of condensate water from the evaporator.
- Support the unit securely.
- If the power cord that is supplied with the unit is not long enough to reach a single receptacle circuit, have another receptacle installed.

Maintenance

CLEANING. All units require periodic cleaning. The cleaning of a window unit is particularly important. Since the condensate water is evaporated very slowly at times, it collects dirt and trash very rapidly. Window units should be removed from the window and cleaned after every cooling season. Usually the water from a hose will clean them adequately; however, in some cases you may have to use an airhose. If water is used, make sure that the fan motor is completely dry before operating the unit. Just a little water in the fan motor windings will cause the motor to burn out. Best results are obtained if steam is used. Steam cleaning requires the following special precautions:

- Be sure that the steam temperature is below the melting temperature of the copper, aluminum, or the solder used on the joints and seams.
- Be sure that the system is completely dry prior to startup of the unit. Steam penetrates better than water and will cause motors to burn out if moisture droplets are left on the inner surfaces of the electrical components.

PACKAGE UNITS

Package air conditioners, see figure 30, are built in sizes from one to 30 tons. This type of equipment is used to cool larger rooms or areas. They may be with or without ductwork. A package unit provides the means for fast and easy conditioning of a large area. If the area is long and narrow or it has partitions or objects that will restrict the airflow, it may be necessary to use ductwork to distribute the air. The main advantage in the use of the package unit is that it can easily be moved from one location to another. For this reason package units are used for mobile equipment due to their ease in moving and ability to become quickly operational.

Major Components

COMPRESSOR. Any of the styles of compressors can be found in package units; hermetic, semihermetic, and open. It is not uncommon to see two compressors in a package unit. Each compressor is independent of the other and feeds a portion of the split evaporator. This type of system is convenient not only to the maintenance man, but it will continue to operate at 50 percent capacity if one of the compressors develops trouble. The maintenance man can isolate the defective system for repair while the remaining portion of the system remains in operation.

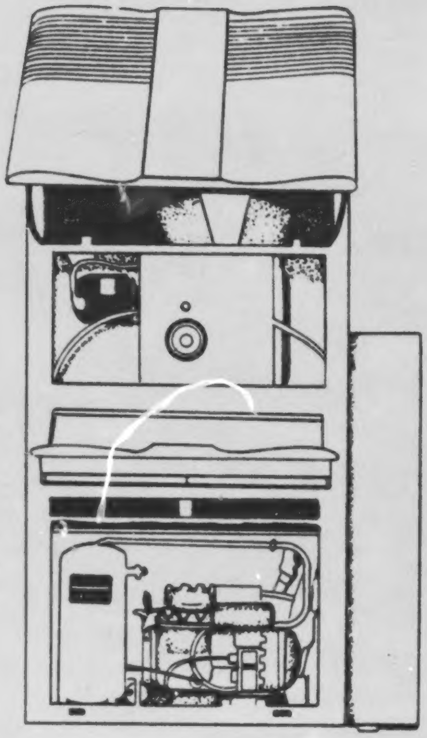

Figure 30. Package Unit

CONDENSERS. The most common is the air-cooled condenser. Refrigerant condensation is obtained by adequate condenser surface and maximum air circulation over the coil and fin surface. The shell and tube water-cooled condenser consists of a gas-type sealed shell containing a copper coil or tubes. The hot refrigerant gas is admitted into the condenser shell and flows down over the condenser tubes in which cooling water is circulated. The refrigerant gas condenses on the surface of the tubes and runs to the bottom of the condenser shell. These condensers are used frequently where the cooling load is heavy and the ambient temperature may rise above 90°F. These units require plumbing connections to both fresh water and a drain or to a water cooling tower, whichever is used. A drain must also be installed for the condensate from the evaporator coil. The flow of water through the condenser is controlled by a water pressure regulating valve which has a small tube connected to the compressor, sensing the head pressure. As the head pressure varies the flow of water varies to maintain a constant head pressure.

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EVAPORATOR AND METERING DEVICE. The evaporators used are usually of the direct expansion type with the refrigerant being metered by the thermostatic expansion valves or capillary tube controls.

BLOWERS. The evaporator blower is usually a squirrel-cage type. In some cases the unit will have two individual blowers to facilitate the air movement. A double blower could be attached to separate motors or be driven by a single motor having a double shaft.

FANS. The condenser fan can be of the squirrel-cage or the propeller type. The fan-blade style will be governed by the amount of heat to be dissipated from the condenser coil, local wind velocities, etc. The condenser fans are usually wired into the circuit through a pressure sensing switch used as a controller. As the pressure increases or decreases, the fan(s) will become active or inactive. This is known as cycling the fan and is one method of capacity control.

MOTORS. There are normally three individual motors found on this equipment: the compressor drive motor, the condenser fan motor, and the evaporator blower motor. If the unit has a water-cooled condenser, then the condenser motor is not required.

POWER REQUIREMENTS. These systems are designed to operate on 220-240v ac, single- or three-phase power. The control circuits will range from 24v to line voltage. A typical package unit wiring diagram is shown in figures 31 and 32.

TROUBLESHOOTING WINDOW AND PACKAGE AIR-CONDITIONING UNITS

Troubleshooting an air-conditioning system is not as complex as it may seem. There are standard procedures, if followed, make it a relatively easy task. By following the recommendations listed below, almost any malfunction can be determined quickly and serviced properly.

Two complaints usually are encountered with air-conditioning units. They are, no cooling and insufficient cooling. Careful study of the following systematic checks should cure these complaints.

1. Reset all controls--set room thermostat below room temperature. If the unit is equipped with manual reset pressure controls, set them for proper operation.

2. Overall electrical checkout--if the unit fails to operate when the control switch is placed in any of the operating positions, check the voltage at the outlet. A test lamp can be used, but a voltmeter is preferable since both no-load and full-load voltages can be taken. Failure to obtain a voltage reading indicates a blown fuse, tripped circuit breaker, or an open in the line between the outlet and the fuse or breaker box. If the fuse is blown, or the breaker is tripped, and blows immediately upon replacement or reset, look for a shorted line in the building wiring. If it blows on plugging in the service cord or turning on the power supply, look for a shorted unit line, capacitor, or motor. Check components to ground with an ohmmeter.

   DO NOT USE THE OHMMETER UNTIL THE UNIT IS DISCONNECTED FROM THE POWER SOURCE.

   IF POWER IS SUPPLIED BY TWO BRANCH CIRCUITS (UNITS WITH SUPPLEMENTAL HEATING), OPEN BOTH DISCONNECTS BEFORE SERVICING.

   To test for grounds, disconnect the service cord and plug from outlet, with an ohmmeter set on the highest scale, test between each side of the service line (not the ground line) entering the chassis and the chassis itself. Care must be taken that the meter probes make good electrical connections to the line and chassis. No continuity should exist between the service line and the chassis, if a ground is indicated by a continuity reading, disconnect the leads to the various components one at a time, and repeat the test until the grounded component(s) are located.

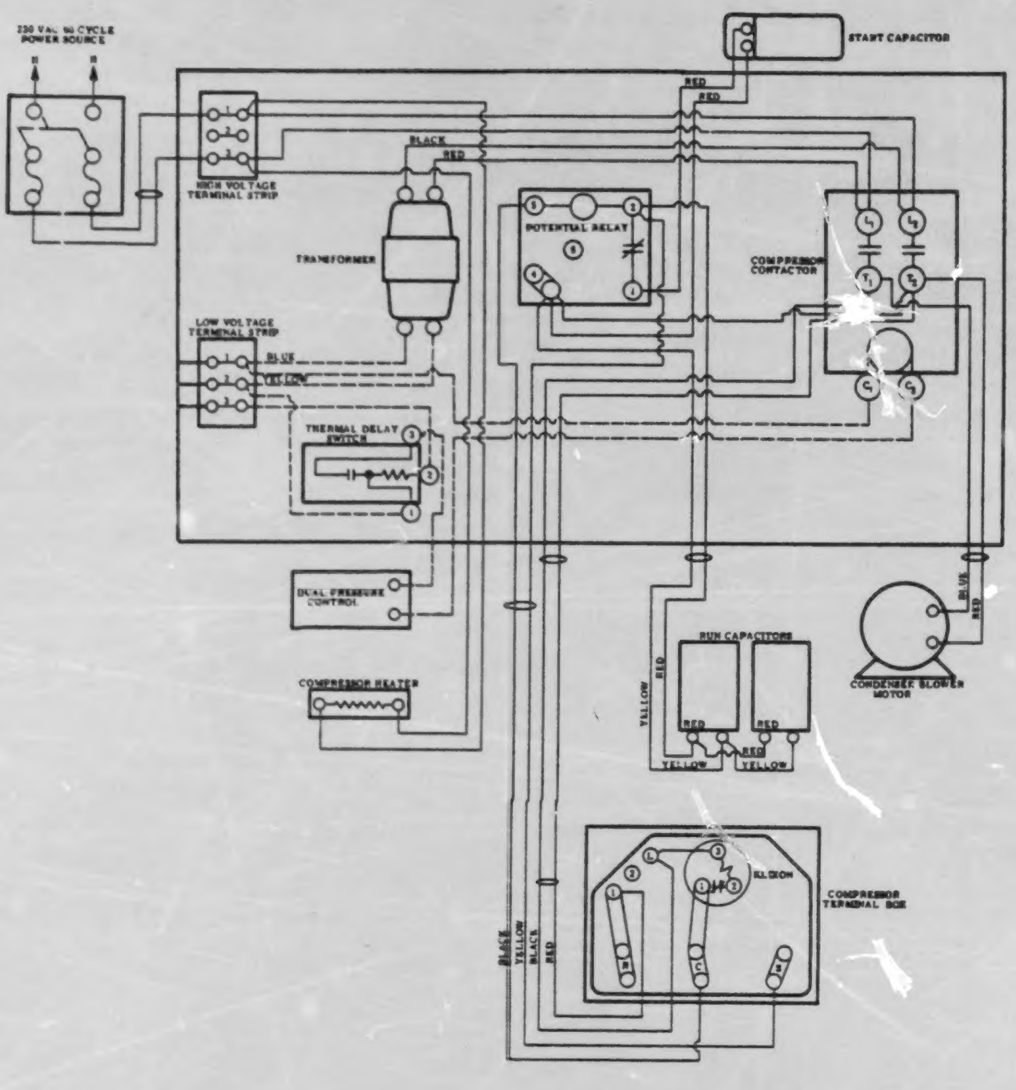

230 VAC 60 CYCLE POWER SOURCE
HIGH VOLTAGE TERMINAL STRIP
1
2
3
BLACK
RED
TRANSFORMER
LOW VOLTAGE TERMINAL STRIP
BLUE
YELLOW
THERMAL DELAY SWITCH
START CAPACITOR
RED
RED
POTENTIAL RELAY
COMPRESSOR CONTACTOR
L_1
L_2
T_1
T_2
DUAL PRESSURE CONTROL
COMPRESSOR HEATER
RUN CAPACITORS
RED
YELLOW
CONDENSER BLOWER MOTOR
BLUE
KLIXON
COMPRESSOR TERMINAL BOX
L
C
BLACK
YELLOW
BLACK

Figure 31. Single Phase - Package Condensing Unit Wiring Diagram

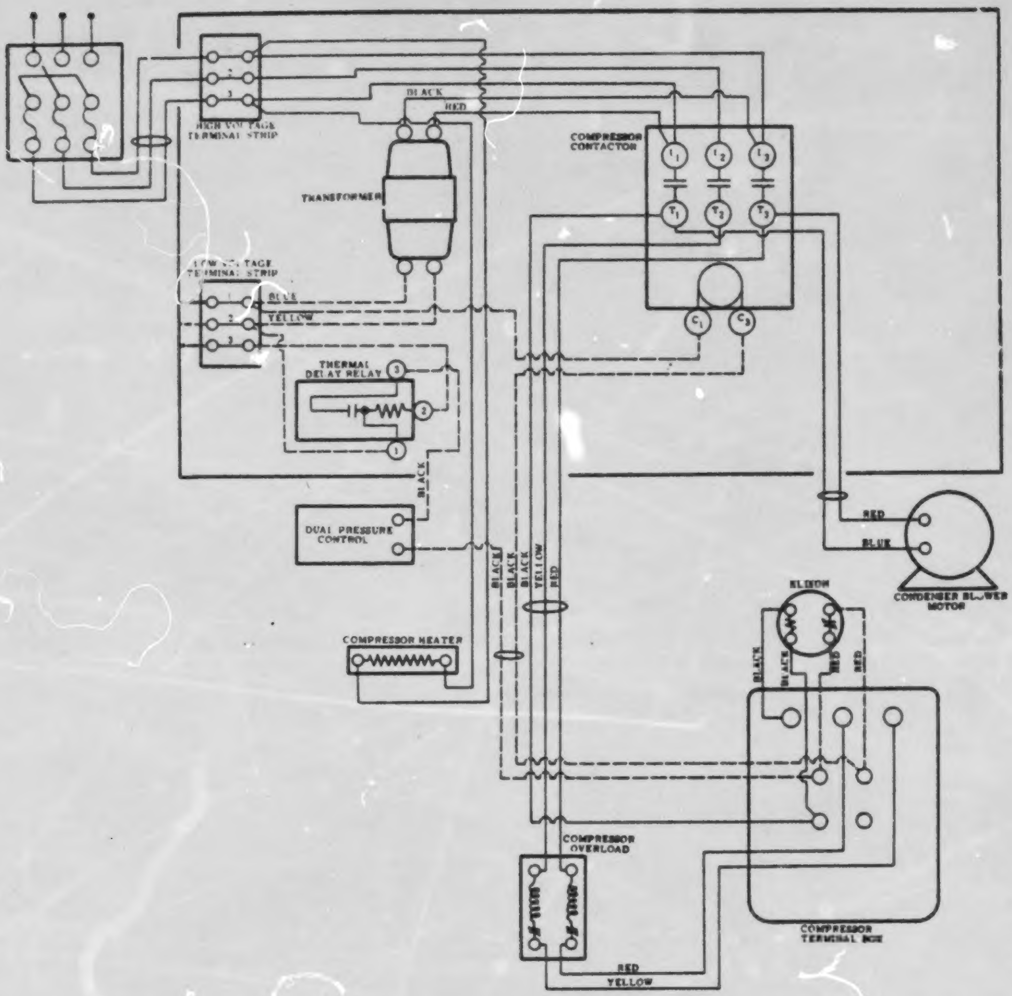

HIGH VOLTAGE TERMINAL STRIP
1
2
3
BLACK
RED
COMPRESSOR CONTACTOR
L_1
L_2
L_3
T_1
T_2
T_3
C_1
C_2
TRANSFORMER
LOW VOLTAGE TERMINAL STRIP
BLUE
YELLOW
THERMAL DELAY RELAY
3
2
1
BLACK
DUAL PRESSURE CONTROL
BLACK
BLACK
BLACK
YELLOW
RED
RED
BLUE
CONDENSER BLOWER MOTOR
KLIXON
BLACK
BLACK
RED
RED
COMPRESSOR HEATER
COMPRESSOR OVERLOAD
RED
YELLOW
COMPRESSOR TERMINAL BOX

Figure 32. Three Phase - Package Condensing Unit Wiring Diagram

If the voltage is normal and the unit operates, use a wattmeter to check the air conditioner's operating efficiency. A low wattage reading indicates that the unit is not delivering its maximum capacity. This may be due to a low refrigerant charge, dirty air filters, inefficient compressor, or a defective fan motor. A high wattage reading indicates a dirty condenser, restricted condenser airflow, defective condenser blower, binding compressor, low voltage, overcharge of refrigerant or noncondensables in the system.

If the voltage at the outlet is normal, and the unit fails to function properly, the trouble will usually be found to be an open circuit. In checking and testing an inoperative unit, start with the most obvious source of trouble and follow through the circuit eliminating each component part, connecting wires, and all connections.

3. Defective relay--the potential relay used on single-phase units have contacts which are normally closed with the unit off but may remain in two positions--open or closed--after the thermostat or control switch stops the unit. The following paragraphs explain the electrical test and the resulting compressor motor operation. If the relay is found to be defective it must be replaced, no attempt to repair these units should be made in the field.

   Starting relay contacts remaining in an OPEN position--The compressor will make a humming sound but will not start if the relay contacts are open; then the thermal overload will open the circuit to the compressor motor. To verify the relay contacts are remaining open, take a piece of No. 12 insulated wire bared at each end and temporarily touch between terminals 1 and 2 on the relay. When the overload resets, voltage will be applied to the start winding. When the compressor reaches operating speed--2 seconds max--REMOVE THE JUMPER.

   The relay can also be checked with an ohmmeter--with the unit power off, and all leads disconnected from the relay, check between terminals 2 and 5. If there is no continuity reading, the relay coil is open and the relay must be replaced.

   Starting relay contacts remaining in the CLOSED position--The compressor will start but will run with a loud growling hum and cycle off on the thermal overload and start again after an interval. To verify the relay contacts are remaining closed, cut off the unit power and while the overload is cooling off, remove the wire from relay terminal 1 to the start capacitor. Reapply power and when, the overload closes, momentarily touch the start capacitor wire to terminal 1 on the relay. When the compressor comes up to speed IMMEDIATELY REMOVE THE START CAPACITOR WIRE. If the compressor operates normally for a period of three to five minutes, then the relay must be replaced. If the unit has cycled for some time as described above, there is a possibility the high potential applied to the start capacitor, due to the relay contacts remaining closed, has caused the start capacitor to break down internally. In such a case neither of the above tests will make the unit operate until the start capacitor is replaced.

4. Defective start or run capacitor--Capacitors fail either open or shorted, without test equipment, the quickest way to check is to substitute a known good one for the suspect capacitor.

   ALWAYS DISCHARGE CAPACITORS BEFORE HANDLING, DISCHARGING IS ACCOMPLISHED BY SHORTING THE CAPACITOR TERMINALS WITH THE BLADE OF A SCREWDRIVER.

Capacitors can also be checked with an ohmmeter as follows. Discharge the capacitor and disconnect the leads. Set the ohmmeter on the highest scale and connect the probes to the capacitor terminals, if the meter needle moves to a resistance reading and falls slowly back to infinity, the capacitor is probably good. If the meter needle swings quickly to the zero end of the scale and stays at or near zero, then the capacitor is shorted. If the needle reads infinity and stays at that position and remains the capacitor is open and in either case must be replaced.

Shorted start or run capacitors will blow a line fuse, or cause cycling on the compressor thermal overload protector. An open start capacitor may do the same. An open run capacitor will not usually affect starting, since the start capacitor supplies enough capacitance to start the compressor motor. Open run capacitors will cause a higher than normal running current and will cause a decrease in motor speed.

Run capacitors are oil filled and the heat from a short, vaporizes the oil into a gas, creating a pressure, which bulges the can. Open capacitors usually have no evidence of failure that can be visually detected. Shorted start capacitors sometimes have ruptured tops and occasionally they may even explode. Use caution while checking capacitors under operating voltages. Another test for a capacitor is to charge it and then discharge it and observe the spark. To perform this test, disconnect the power from the unit and remove the capacitor from the electrical circuit. Momentarily charge the capacitor with a fused test cord. If the test cord fuse blows the capacitor is shorted. If the fuse doesn't blow, short the capacitor with a screwdriver; the capacitor should discharge with a hot spark. No spark at all indicates the capacitor is open. A weak spark indicates a loss of capacity, in either case the capacitor must be replaced. A run capacitor can also be tested using the above procedure.

5. Compressor stuck--This is a difficult thing to determine on hermetic compressors. The best method is to check all other components that might cause the compressor to stick; motor windings, start relay, capacitors, and wiring. If no fault can be determined and the compressor draws its Locked Rotor Amps (LRA) rating it is usually assumed the compressor is stuck.

Checking compressor motor--To check for open windings, touch one lead of the ohmmeter to the common terminal of the compressor and the other lead to the start and run terminal in sequence, a continuity reading must be obtained on each test. To check for shorted windings, set the ohmmeter on a low scale, shorts can be anything from partial to direct. A partial short will give a low reading on the ohmmeter; a direct short will read very close to zero. Shorts cause heavy current draw and may result in compressor burnout. To check for grounded windings, scrape a spot on the compressor motor body free of paint to obtain good contact point. With the power on, touch one lead of a test light to the common terminal and the other lead to the compressor body. The lamp should not light, if it does light one of the windings is grounded.

If no fault can be found in the windings and the compressor still will not run, the trouble may be a stalled motor. A stalled motor will draw excessive amperage, causing the thermal overload protector to open. If the stall is minor, it is sometimes possible to free the motor by opening and closing the circuit switch several times. Sufficient time should be allowed between tries to allow the overload protector to cool and snap closed.

If the unit has been operating under extreme load conditions for a period of time and fails to restart, sufficient time must be allowed for the refrigerant system to equalize, to reduce the starting torque requirement. If the compressor fails to start after an equalization time, momentarily reverse the run and start leads. Try this several times and if the motor starts, rewire it correctly and operate several times to be sure everything is satisfactory. If the trouble is not remedied by this test, the compressor must be replaced.

Three-phase units--After checking the circuit breakers, fuses, overload protectors, pressure controls, operating controls, and line voltage, and the compressor will not start, you may assume the compressor is at fault. To verify this, the compressor must be checked for open, shorted, or grounded windings using the test procedures outlined for single-phase units.

6. Defective or incorrect wiring--Occasionally there are intermittent types of electric troubles, such as loose or broken wires which are found by a careful check of the entire electrical circuit and every connection. As far as incorrect wiring is concerned, the only sure way is to check the wiring diagram carefully.

7. Blown fuse, three-phase equipment--If one fuse is blown and the compressor motor tries to start, locked rotor amperage will be drawn which will either blow another fuse or trip the motor overload protector. Replace the defective fuse or fuses and try to start the compressor again. If the compressor starts and draws normal amperage, a temporary voltage unbalance may have existed between phases which caused the fuse to blow. A marginal-sized fuse may also have been installed. Check the equipment manual and install the correct size fuses.

   If the problem continues to exist, check the line voltage to the unit. Checking line voltage is extremely important before installing or servicing any air conditioner. Before the unit is installed, no load and full load voltage must be checked. For this check, a load checker which simulates full-load condition is recommended. For single-phase units the voltage must not differ more than ± 10 percent from that specified on the data plate; on three-phase sources there must not be more than a 3 percent variation between phases. The service specialist must also check the line voltage when servicing the unit, because the line may have been overloaded after the unit was installed. Overloaded lines cause low voltage and create potential fire hazards. Low voltage will cause the unit to draw excessive amperage which in turn will cause the built-in protective devices and relays to operate erratically and eventually fail.

   When checking a three-phase unit on a 208-volt line, care should be taken that the 208-volt tap on the low voltage transformer is used. If low voltage is encountered, and is the result of overloaded lines, the condition must be corrected. If low voltage is the result of the supply lines, the power company must be notified for correction.

8. Burned starter contacts, three-phase equipment--Contacts can close mechanically, but still not conduct electrically. This could happen if the contacts were burned. To test for this condition, measure contact resistance with an ohmmeter set for the lowest scale, with the starter contacts closed.

   REMOVE ALL WIRES FROM TERMINALS BEFORE MEASURING CONTACT RESISTANCE.

The meter should read zero ohms; if the meter does not read zero ohms the contacts must be replaced.

9. Open overload--The overload protector can be tested in the field only for continuity. This can be accomplished by using a test cord, or an ohmmeter. If there is continuity through all contacts, they assume the protector is in operating condition. The test should be performed with all electrical connections removed from the protector. The quickest and easiest way to test an overload is to replace it with a new one. If the new one trips off after a few seconds, the fault may lie in the compressor, relay, or start capacitor. In fact, if an overload opens to stop a motor the chances are it is working properly.

10. No voltage to contactor coil--Some units use contactors whose coils operate on 24 volts, others operate on line voltage. If the operating voltage is not known, set the voltmeter scale to at least 250 volts before measuring voltage at the contactor coil. This will prevent meter damage. If the coil is the low voltage type, lower the meter setting.

11. No power to control circuit--Every control system has a power source. This can be a low voltage transformer to control gas valves in furnaces and sometimes a transformer where a separate cooling application is used. Sometimes line voltage is used. Locate the power source, and measure the voltage to determine if it is proper.

12. Open pressure control--To determine if the low pressure control is open, remove the wire from the low-pressure switch and check with an ohmmeter set on the RX1 scale. The meter should read zero ohms if the switch is closed. If the switch is open, it may be from a lack of refrigerant. Check the pressure gages. If the pressure is below 25 psig, there has been a loss of refrigerant. Locate the leak and repair. If the switch is still open, it is defective and must be replaced.

13. Lockout relay contacts open--When a lockout relay is used it is necessary to break and remake the room thermostat circuit to reset this relay. If this does not close the lockout relay circuit and start the unit, the relay contacts are bad or the relay coil is open. To check the relay, measure contact and coil resistance. If contact resistance is greater than zero, or coil is open or shorted (zero ohms) replace relay.

14. Room thermostat open--If a line voltage thermostat is used, its connections can be easily jumped at the unit or at the thermostat. In a combination heating/cooling thermostat with a subbase (low-voltage type) jumper the cooling terminals at the thermostat. If the unit starts, look for trouble at the subbase or thermostat. Make sure the thermostat is located properly, and the subbase is perfectly level as this can affect calibration.

15. Heat/cool interlock open--Many units are installed to operate in combination with a warm air furnace. An interlock switch is sometimes used to prevent operation of both units at the same time. These units will be discussed in the next unit of instruction.

16 Open in control circuit wiring--Using the unit wiring diagram, make a terminal to terminal check for continuity. To avoid erroneous indications each circuit must be isolated before testing.

17. Contactor coil open--When voltage is applied to a contactor or magnetic line starter coil and the coil will not close the contacts, it may be due to an open coil. To check for this condition, carefully push the contacts closed with an insulated screwdriver or wooden stick. If the unit starts the coil may be bad. To verify, remove the wires and check for coil continuity with an ohmmeter. If the coil tests open, replace it. If the coil has checked open, it has usually burned out; check for the cause. Do not make a replacement without finding the cause, or the replacement will also burn out. The contactor mechanism must be cleaned before the coil is replaced.

18. Contactor coil buzzing--This indicates the contactor or magnetic coil is energized, and pulled in, but is not holding it in. Measure voltage at the coil. If it is normal, the contactor armature is either fouled or the mechanism is binding or tight. Sometimes, insulation material from overheated coils drips on the moving parts of the contactor and fouls the operating mechanism. Contactors with 24-volt coils cannot operate if the voltage to the contactor falls below 21.6 volts. Check the volt-ampere rating of the 24-volt transformer. The volt-ampere rating is stamped on the transformer and should be at least 30 VA for contactor coil duty.

Thermostat wiring which is too long is also a possible cause for low voltage. Eighteen-gage solid copper wire is the minimum size when the total length of the control circuit does not exceed 120 linear feet. Use larger wire if the run is over this value.

19. Defective compressor valves--Any failure of the compressor valves will cause low head pressure, high suction pressure, low amperage, and poor cooling. Methods of checking compressor valves were discussed previously.

20. Poor expansion valve bulb location of TEV bulb refer to unit of instruction, Day 11.

21. Initial pulldown--High suction pressure is a characteristic of startup and initial pulldown. This is due to the high sensible temperatures and high humidity loads on the evaporator. Gradually the sensible and latent heat loads will be reduced and this will reduct the suction pressure.

22. Too much air over evaporator coil--Most suction pressures given by manufacturers are based on standard conditions. The air over the coil should be 400 cfm per ton of unit capacity at a temperature of 80°F dry bulb and 67°F wet bulb. Under test conditions the sensible air temperature drop with some condensate flowing from the evaporator should be 18 to 22°F.

If the airflow is too great, the sensible temperature drop across the evaporator will be low with little or no condensate. Reducing the blower speed, where equipment allows should increase the temperature drop, increase condensate flow, and decrease suction pressure.

23. Excessive refrigerant charge--An overcharge is difficult to detect in cool weather. This can be explained by discussing what happens to any refrigerant excess. An excess stays in the bottom of the condenser as a subcooled liquid. This excess takes up valuable heat exchange surface, which is needed during hot weather. But because the air or water passing over the condenser is cool and condensers are large, the heat exchange surface may be adequate for light loads. Thus this symptom is likely to show up only when the weather gets warmer and the load increases. The amount of overcharge is impossible to determine. The symptoms are high head pressure, high amperage draw for the temperature existing at the condenser. Once it has been determined that an overcharge exists, proceed as follows.

    Check the manufacturer's specifications for correct suction and head pressure characteristics. Install a manifold gage assembly. Insure the load on the evaporator is moderately heavy, 80°F dry bulb or greater. Check the pressures, which should not exceed manufacturer's specifications by more than 5 psig. If the system pressures indicate an overcharge, bleed the refrigerant until the pressures are correct. If the system has a sight glass, the sight glass may also be used; however it is not considered economical because the system is bled until bubbles appear in the sight glass and then the system must be recharged until the bubbles disappear indicating a correct charge.

24. Tight compressor--Occasionally a new compressor may draw more running amperage than normal for existing conditions. This condition may clear up after a break-in period. If the motor current continues to be excessive, the compressor is defective and must be replaced.

25. Discharge line or condenser passes restricted--This can be compared to putting a valve in the discharge line leaving the compressor. The more the valve is closed, the more resistance the compressor must overcome. To solve this problem, the obstruction must be found and removed.

26. Low air or water flow through the condenser--Low airflow through an air-cooled condenser causes high head pressure and excessive amperage draw. The condenser must remove the heat effectively. Examine the installation to be sure the air passes are not blocked by dirt or foreign objects. Placement of the condenser must be so as to not cause an air obstruction or high wind problem. Low waterflow through a water-cooled unit will cause the same symptoms as low air through an air-cooled unit. On straight waste systems the waterflow must be adjusted to maintain its temperature to 95°F leaving the condenser. On cooling tower systems, the waterflow rate is determined by two factors; which were discussed in day 11.

27. Recirculation of condenser air--Check air temperature at the inlet to the condenser; then check the air temperature well away from the condenser. If temperature readings are not the same, recirculation is occurring. Reinstall, if possible, so that proper circulation can be obtained.

28. Defective condenser fan motor or fan capacitor--Before any condenser motor is changed, a series of tests must be made. Are the bearings tight? Spin the fan blade with the power off. The fan should rotate freely for a few seconds. If the fan is tight, it may be from a lack of oil; lubricate with SAE 10-20 oil. If oiling does not cause the motor to turn freely, check the bearing for damage or seizing. If the motor turns freely with no applied power, the capacitor should be checked using the procedure discussed previously. The motor should also be checked for open, shorted, or grounded windings.

29. Improperly wired condenser fan motor--If the motor was changed, check the wiring against the wiring diagram.

30. Wrong voltage to condenser fan motor--If a 230-volt, single-phase condensing unit is installed on two legs of a 3- or 4-wire 208-volt network, this is a definite misapplication of equipment. The remedy for this is a costly one. To remedy this, a motor designed for 208 volts could be installed or the complete unit replaced with a three-phase 208/220-volt unit. In some cases a boost and buck transformer has been used to increase the voltage to the fan motor. This problem can be eliminated entirely if careful attention is given to the voltage available before the motor is installed. When low voltage is applied to a fan motor, it runs more slowly and does not move the required amount of air through the condenser. In hot weather, this causes the head pressure to rise, increasing operating costs and possible tripping of the high pressure control. The same voltage conditions that affect the condenser fan motor also affect the compressor motor. A straight 230-volt unit is not designed to operate at 208 volts.

31. Air in the refrigerant system--Use the procedure discussed in earlier units for this trouble.

32. Low airflow through the evaporator--USUALLY ACCOMPANIED BY A FROSTED COIL AND SUCTION LINE. In order to obtain the proper suction pressure, air should move across the evaporator at 400 cfm per ton of refrigeration capacity. Too little air will cause too little heat to be absorbed by the evaporator. If the air is not being cooled more than 22°F suspect insufficient air across the evaporator. Low airflow is a situation that can be caused by many things, when it occurs the temperature of the coil surface is reduced below the freezing point, the accumulation of frost further reduces the airflow and eventually the coil is completely blocked with ice. In considering this trouble, thought must be given to all the things that can reduce airflow. Some are obvious, others are harder to find. A thorough check of the following must be made. Condition of the filters, fan belt for slippage, blower for correct rotation, current draw on blower motor to determine if it is overloaded. Check the blower speed and increase by closing the motor pulley sheaves, checking the motor current draw after each adjustment. Nameplate amperage must not be exceeded by more than 10 percent. If this does not correct the condition, a thorough check of the ductwork and registers should be made for proper adjustment. It may be that the ductwork is inadequate, a heat gain calculation and cfm requirement check should be made.

33. Discharge air register stratification--To determine whether stratification cooling is occurring, measure the temperature at floor and ceiling heights. If the temperature difference is greater than 5°F, stratification is present. Register location is very important for proper operation. For example, low sidewall registers do not usually work too well for cooling unless the register louvers are adjusted to throw the colder and heavier air up where it can mix with the air near the ceiling. Unless this is done, the cool air will leave the register, cling close to the floor and spill into the return air without ever cooling the room. Good mixing of cool conditioned air is necessary no matter where the registers are located. A rule-of-thumb for registers is 600 to 700 fpm for cooling applications. Velometers and anemometers can be used for setting registers. Restricting the registers too close can cause whistling noises. For this reason, careful adjustment is required to avoid curing one complaint and causing another.

34. Low outside temperature--There are applications where there can be a very high internal load when the outside air temperature is quite low. This occurs when there is a high concentration of people such as in theaters, meeting rooms, etc. When a condensing unit is operating with low outside temperatures, the capacity will be reduced because the unit will cycle on the low pressure control and therefore not be running all the time. The compressor can be kept running all the time the thermostat is calling for cooling by using a pressure control which closes on a pressure rise and opens on a pressure fall. This control is installed to start and stop the condenser fan or fans in response to these conditions. Other methods of condenser capacity control were discussed previously.

35. Low refrigerant charge--Measure the temperature drop across the evaporator. It should be 18 to 22°F. Check suction and discharge pressures and sight glass, if one is installed. Consult manufacturer's specifications for proper pressures.

36. Restrictions in capillary tube or refrigerant expansion valve distributors--There are several symptoms indicative of this condition. First check suction pressure. A lower than normal suction pressure is one symptom. Next temporarily shut off evaporator blower motor and allow the condensing unit to operate. If there are no restrictions, the evaporator will frost uniformly across its surface. If restricted, those sections that are restricted will not frost. To remove the restriction, pump the unit down to 2 psig. Remove the capillary tube or expansion and repair or replace, also install a new drier.

37. Liquid line restricted--Restriction of the liquid line results in a starved coil, this in turn results in low suction pressure and a temperature across the coil exceeding 18 to 22°F.

38. Drier restricted--Feel the drier with your hand or take a measurement of the temperature at the inlet and outlet of the drier for an indication of its condition. Any noticeable temperature difference indicates a restricted drier.

39. Suction line restricted--A restricted suction line is indicated by low suction pressure. Sometimes refrigerant lines are restricted by flattening the lines when bending during fabrication or with some object accidentally. Examine all parts of the line for physical evidence of damage. The best check is to actually measure the suction line pressure drop. This procedure was discussed in the classroom in an earlier unit of instruction.

40. Superheat setting too high--The superheat setting for air conditioning is normally 10°F. A setting higher than this warrants valve adjustment. Superheat setting was discussed in a previous unit of instruction.

41. Overheated compressor--Sometimes on a hot day, the compressor overload will trip due to an undercharge of refrigerant. The gas returning to the compressor motor windings will have a higher superheat due to the undercharge. The higher superheat gives inadequate cooling to the motor which causes the overload to trip. In this situation, the suction pressure will be lower than normal, but not low enough to cause the low pressure switch to open. In this case, the unit was undercharged originally, or there is a leak. On an undercharged unit always look for a leak first, the if a leak is not found it is obvious what has happened.

42. High ambient temperature around the magnetic starter--The overload protectors in the magnetic starters are not temperature compensated. Thus if they are installed in extra warm locations, they will trip at lower than normal currents. Conversely, if they are installed in a cooler than normal location, more current is required to trip them. The first situation causes nuisance tripping; the second causes damaged compressors and motors. Always install a magnetic starter in a place where uniform temperatures are existing and do not exceed 95°F. DO NOT USE OVERLOADS WITH HIGHER RATINGS THAN THOSE SPECIFIED BY THE MANUFACTURER.

SUMMARY

This unit of study has presented the fundamentals of the various operations and applications of window and package air-conditioning systems. In addition, the installation, maintenance, and troubleshooting information provided can be of considerable help to the serious student of these systems.

REFERENCES;

Textbook; Modern Refrigeration and Air Conditioning, Althouse, Turnquist, Bracciano

OBJECTIVES

This study guide will aid you in learning the operation, service procedures, troubleshooting, and repair of residential type air-conditioning systems.

INTRODUCTION

It is not your primary duty to service and repair furnaces. However, since the furnace is often an integral part of the air conditioner, it is necessary to understand the operation of the furnace to service the air conditioner. The unit that will be discussed in this study guide is a 100, 000 Btu gas-fired furnace and a 38, 000 Btu electrical air conditioner.

HEATING AND COOLING SYSTEM

Since the heating and the cooling are produced in the same portion of the package (the furnace body), let's look at the overall basic structure of the combined units as shown in figure 33. The following are used by both heating and cooling operations.

Air Distribution

Air conditioning requires that the right amount of conditioned air be supplied to each room or space, to maintain the desirable conditions of temperature, humidity, and air movement. No matter how accurately the cooling and heating unit is selected, or installed, good unit performance will result only if the distribution system is properly designed and installed. Good distribution systems require ductwork with registers and grilles to accomlish the desired results. Residential heating/cooling systems always require some type of duct system which usually will contain the following.

THE RETURN PLENUM. Air is returned to the plenum either by ducts or velocity pressure from the controlled space for reconditioning.

THE FILTER SECTION. In this section the dust, lint, and other foreign materials are filtered out of the air prior to reconditioning.

THE BLOWER SECTION. This section contains the unit used to convey the air through the active conditioning process and recirculates it back to the space being controlled.

THE HEATING OR COOLING SECTION. This is where the air is conditioned to the desired temperature.

THE SUPPLY AIR PLENUM. In this section, the reconditioned air is collected prior to being distributed into the various parts of the house or building.

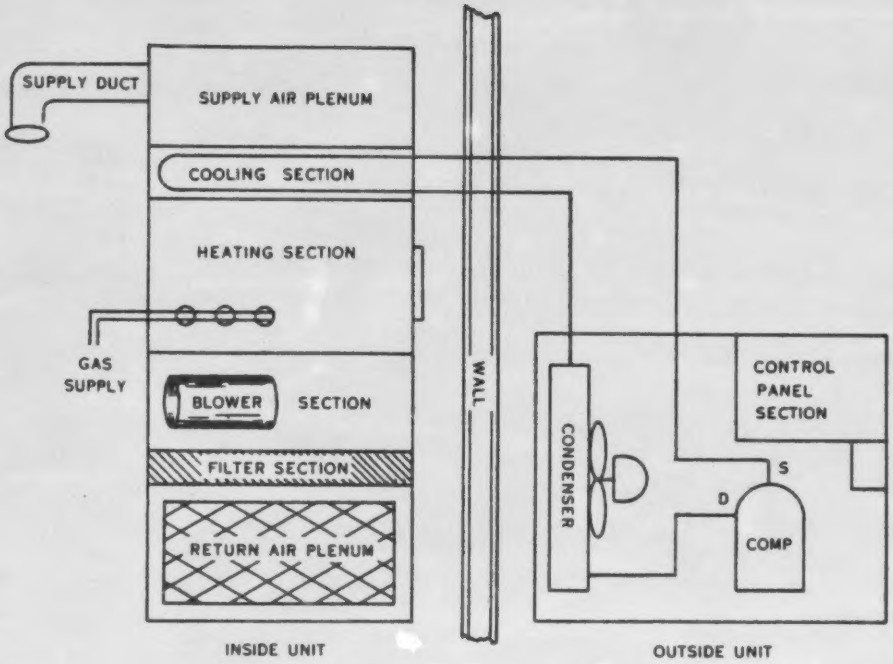

SUPPLY DUCT
SUPPLY AIR PLENUM
COOLING SECTION
HEATING SECTION
GAS SUPPLY
BLOWER
SECTION
FILTER SECTION
RETURN AIR PLENUM
INSIDE UNIT
WALL
CONDENSER
CONTROL PANEL SECTION
S
D
COMP
OUTSIDE UNIT

Figure 33

2F 10-12

THE SUPPLY DUCTS. Supply ducts are used to convey the reconditioned air to the rooms being serviced. They are normally round in construction and are insulated to prevent heat gain or heat loss between the controlled variable and the system. Each of the ducts are supplied with a balancing damper in the outlet from the plenum and a room damper in the outlet extending into the controlled space. The balancing damper is there to insure that the proper amount of air enters the controlled space to achieve the desired condition.

THE DUCT OUTLETS. Duct outlets in each room contain a grille device to uniformly distribute the pattern of airflow to achieve maximum results. There are several types of outlets depending on the design of each application.

A review of the units of instruction covered on Days 16 and 17 will answer any questions you might have concerning the sizing and adjustments of ducts and air distribution systems.

Cooling System

The cooling system consists of an electrical air-conditioning unit. It has a capacity of 38,000 Btus per hour. This size unit is adaptable to Capehart or Wherry housing units found on most bases. It can adequately cool a floor space of 1500 to 1800 square feet. This figure is derived from the general rule of thumb for use with smaller air-conditioning systems or one ton of refrigeration will cool 600 square feet. The air conditioner is divided into two major sections. The condensing unit section is mounted outside of the house on a concrete slab, and the evaporator section is mounted in the supply air plenum above the furnace body.

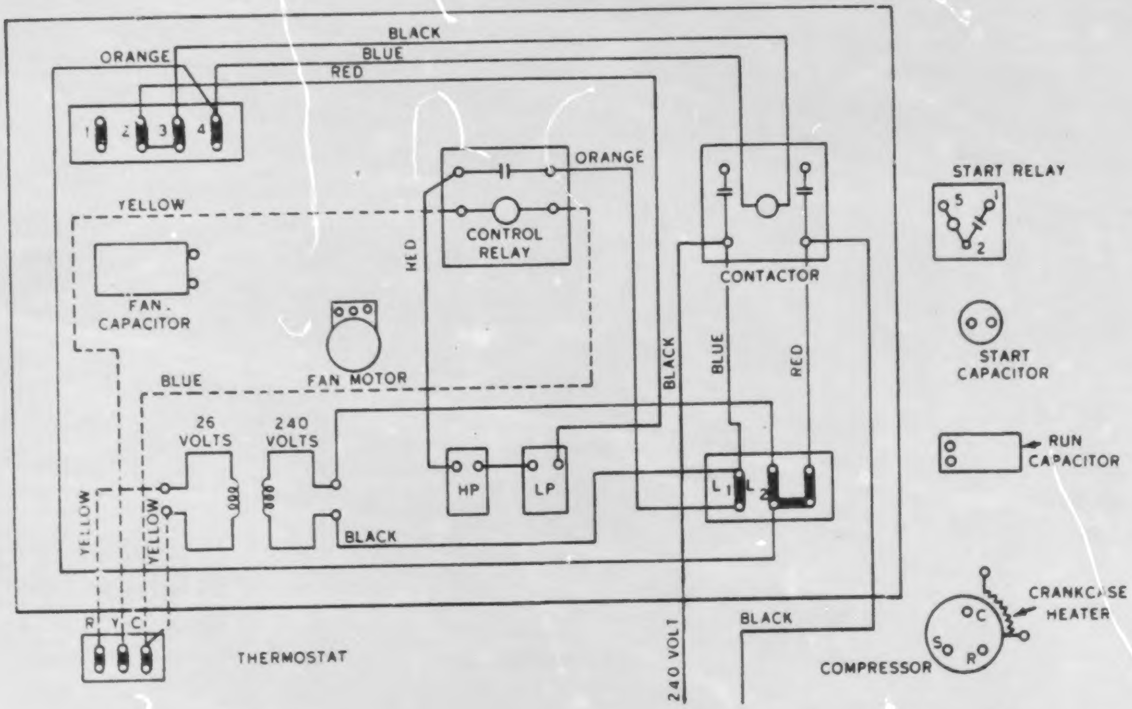
CONDENSER. The condensing unit is really very simple in makeup and resembles a window unit in construction except that the evaporator isn't inside the unit body. Components contained in the condensing unit are: condenser coil, compressor, condenser fan and fan motor, controls, wiring, and tubing. The evaporator section consists of the evaporator coil and TEV or capillary tube depending on the type of metering device required by the unit.

COMPRESSOR. The compressor contains high-speed hermetically sealed motor and is very efficient if all proper procedures and precautions are followed. A crankcase heater is installed around the compressor body to keep the oil warm, thus keeping the liquid refrigerant boiled out of the oil at all times. If the current flow to the heater is interrupted, the oil must be reheated the same length of time as the interruption--up to 12 hours. The heater must be operated 12 hours prior to startup on the system following shutdown. No more than 12 hours are required to heat the oil at any time.

CONTROLS. All of the controls are located in the control panel within the condensing unit. By removing the control panel cover, it is possible to see everything but the condenser and fan. The unit is equipped with a stepdown transformer, but in this application it is not used. The control voltage is drawn from the transformer of the furnace. The same circuit is wired in series with the dual-purpose thermostat.

Condensing Unit Current Flow

CONTROL CIRCUIT. The control circuit consists of two separate circuits. One of these is a 26v circuit and the other is a 240v circuit, see figure 34. In the low voltage (dashed lines) circuit, current flows from the transformer (yellow) to terminal C on the thermostat subbase, to the control relay coil (blue), back through the thermostat (yellow), and returns to the transformer (yellow) to complete the 26v circuit. If the thermostat is calling for cooling this will energize the coil of the control relay, close the contact points and energize the 240v circuit (solid lines). This will allow current to flow from line to the bottom of the contactor (black), to L_2 on the terminal block (red), to terminal 4 on the other terminal block (orange), to the holding coil on the contactor (blue), back to terminal 3 (black), to terminal 2 to the low pressure and high pressure controls (red), to the points on the control relay (red), to L_1 on the first terminal block (orange), back to the bottom of the other side of the contactor (blue), and returns back to line. This will close the contact points on the contactor sending power to the compressor and fan.



BLACK
BLUE
RED
ORANGE
1
2
3
4
ORANGE
YELLOW
CONTROL RELAY
RED
CONTACTOR
START RELAY
5
1
2
FAN CAPACITOR
FAN MOTOR
START CAPACITOR
BLUE
BLACK
BLUE
RED
26 VOLTS
240 VOLTS
HP
LP
L_1
L_2
RUN CAPACITOR
YELLOW
YELLOW
BLACK
CRANKCASE HEATER
C
S
R
R
Y
C
THERMOSTAT
240 VOLT
BLACK
COMPRESSOR

5B 10-120

Figure 34.

POWER CIRCUIT. The power circuit is composed of three separate circuits. These are the crankcase heater circuit, the condenser fan circuit, and the compressor circuit, see figure 35.

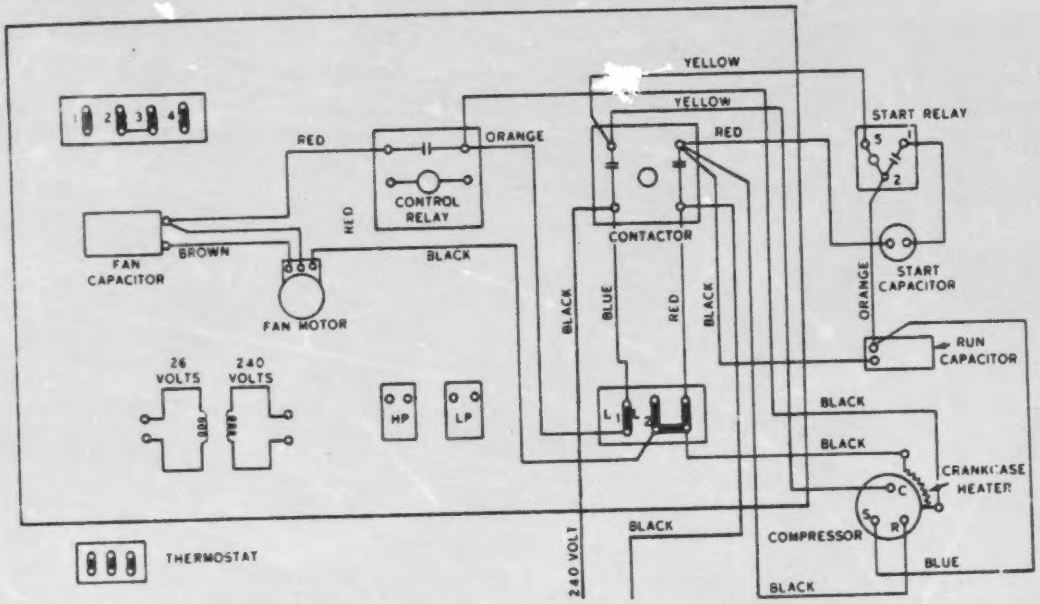

1 2 3 4
RED
ORANGE
CONTROL RELAY
RED
FAN CAPACITOR
BROWN
BLACK
FAN MOTOR
26 VOLTS
240 VOLTS
HP
LP
THERMOSTAT
YELLOW
YELLOW
RED
CONTACTOR
BLACK
BLUE
RED
BLACK
START RELAY
5
1
2
START CAPACITOR
ORANGE
RUN CAPACITOR
BLACK
BLACK
L1
L2
CRANKCASE HEATER
C
S
R
COMPRESSOR
BLACK
BLUE
BLACK
240 VOLT

Figure 35. Power Circuit

Crankcase Heater. This circuit is energized whenever the main switch to the unit is closed. Current flows from line to the bottom of the contactor (black), to L_2 on the terminal block (red), to the crankcase heater (black), to the control relay (black), to L_1 on the terminal block (orange), to the bottom of the other side of the contactor (blue), and back to line (black).

Condenser Fan. Current flows from line to the bottom of the contactor (black), to L_2 on the terminal block (red), to the fan motor (black), and the fan capacitor (brown), to the contact points on the control relay (red), to L_1 on the terminal block (orange), to the bottom of the other side of the contactor (blue), and back to line (black).

Compressor. Current flows from line through the contactor to the start relay, capacitors, and compressor. This unit operates the same as the unit explained in Block I with a potential relay. The points are closed on start allowing current flow to go to the start capacitor and start winding. As the motor picks up speed, the points are opened by the relay coil stopping the applied current flow to the start winding and removing the start capacitor from the circuit. Figure 36 shows the complete wiring of the condensing unit.

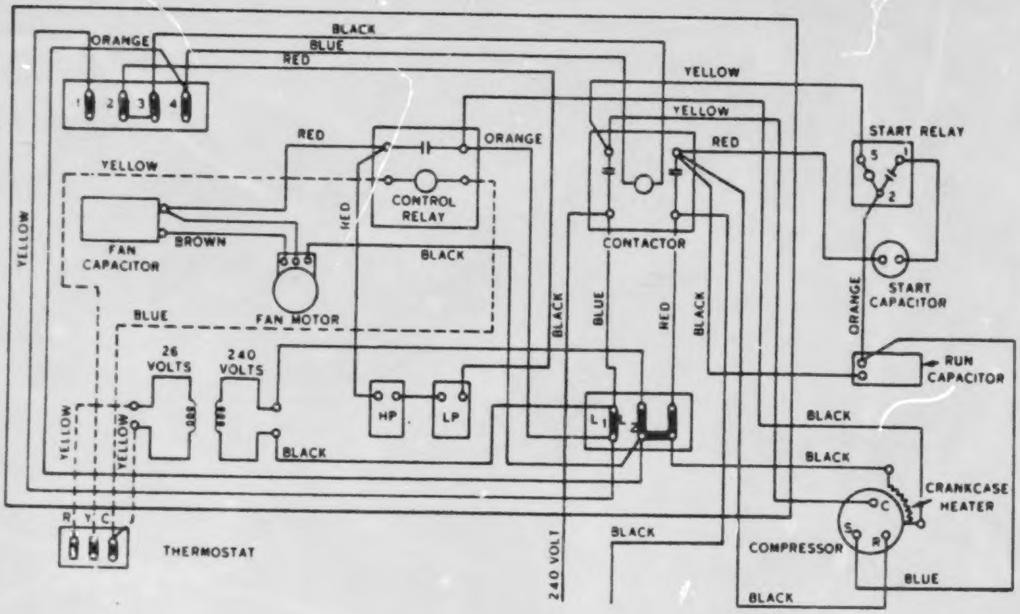

ORANGE
BLACK
BLUE
RED
YELLOW
1
2
3
4
YELLOW
START RELAY
5
1
2
RED
ORANGE
CONTROL RELAY
RED
CONTACTOR
YELLOW
FAN CAPACITOR
BROWN
FAN MOTOR
BLACK
START CAPACITOR
ORANGE
BLUE
26 VOLTS
240 VOLTS
HP
LP
BLACK
BLUE
RED
BLACK
RUN CAPACITOR
L1
L2
BLACK
BLACK
CRANKCASE HEATER
C
S
R
COMPRESSOR
BLUE
BLACK
BLACK
240 VOLT
R
Y
C
THERMOSTAT

Figure 36. Complete Condensing Unit Wiring

HEATING SYSTEM

The heating system consists of a gas-fired furnace rated at 100, 000 Btu per hour input at the burner and 80, 000 Btu per hour output into the controlled space. See figure 37 for the component locations.

Component Functions

THE FURNACE BODY. It consists of the outside shell and the structural members.

THE GAS PRESSURE REGULATOR. This regulator is a diaphragm type gas valve located in the gas line. Its purpose is to supply gas at a constant pressure to the burners.

The type of gas used in the furnace burners is dependent upon local gas usage. It can operate on natural or bottled gas. If the type of gas is changed, the jets in the burner must be changed to accommodate the new type of gas.

THE GAS VALVE. The gas valve is a two-position solenoid valve and is used to control the flow of gas to the burners.

THE GAS BURNERS. The burners are made of cast iron with several holes or (outlets) evenly distributed along their length. The majority of gas burners are the Bunsen type and operate with a nonluminous flame. The air supply must be adjusted so that all the gas is consumed in the combustion chamber. Unburned gas causes carbon deposits to clog up the heat exchanger.

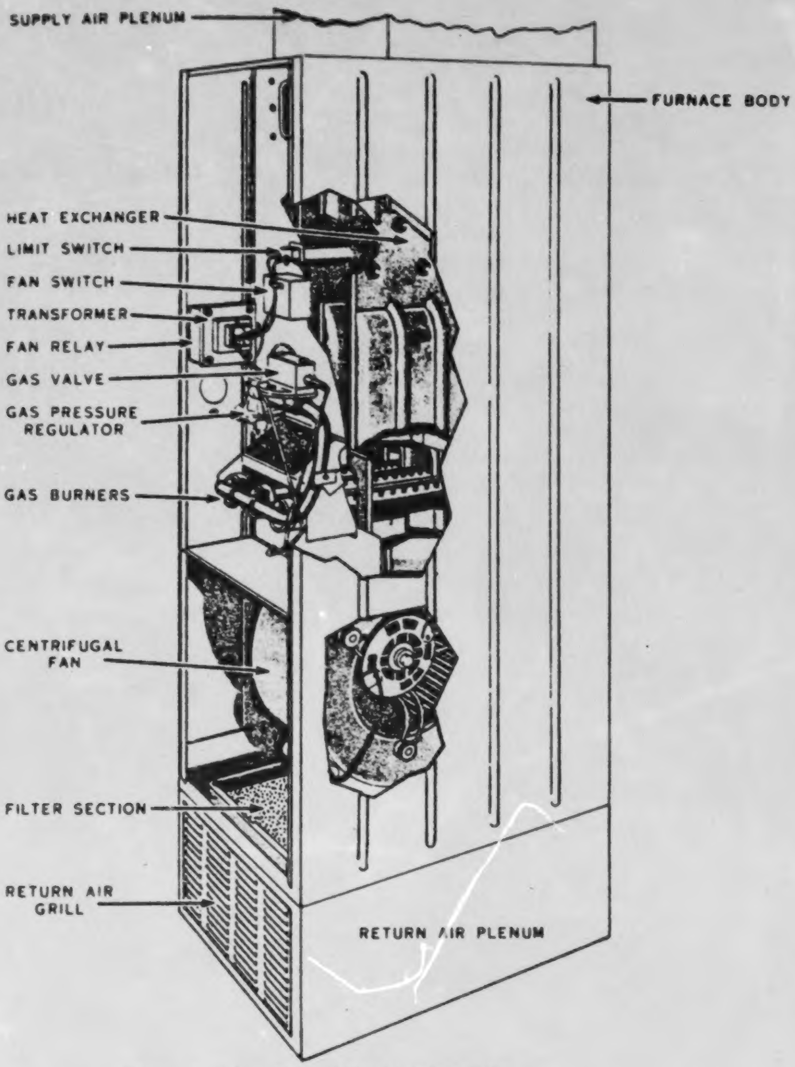

SUPPLY AIR PLENUM
FURNACE BODY
HEAT EXCHANGER
LIMIT SWITCH
FAN SWITCH
TRANSFORMER
FAN RELAY
GAS VALVE
GAS PRESSURE REGULATOR
GAS BURNERS
CENTRIFUGAL FAN
FILTER SECTION
RETURN AIR GRILL
RETURN AIR PLENUM

Figure 37. Gas-Fired Furnace

THE FAN. It is of the centrifugal forward curved type and draws air from the return plenum forcing it through the heat exchanger and out the ducts to each room.

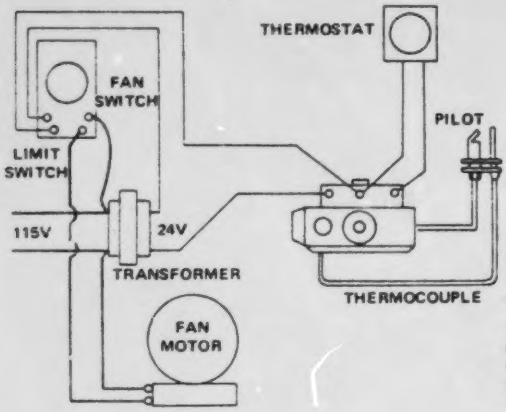
THE HEAT EXCHANGER. The heat exchanger consists of two completely separate sections. The fire is produced in one section and the conditioned air is passed through the other section.

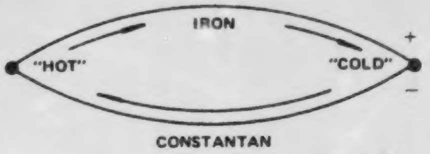
THE TRANSFORMER. The transformer has a primary voltage of 120v ac and a secondary voltage of 26v ac and a capacity rating of 40 VA. It supplies the control circuit for both the cooling and heating cycles.

THE FAN SWITCH. The fan switch is used during the HEATING CYCLE ONLY. The switch has a bimetal element that closes on a rise in the temperature. The bimetal element is extended into the heat exchanger to sense the temperature (changes) and cycle the blower fan.

THE LIMIT SWITCH. This switch is a high temperature safety device. If the temperature inside the heat exchanger exceeds 200°F, the limit switch will open and cause the gas valve to close stopping the burner flame.

THE PILOT LIGHT. There are two types of flame safety devices activated by the pilot light flame. They are the thermocouple and thermopile. When the thermocouple is heated by the pilot flame, the thermocouple produces millivolts that energizes a magnet coil in the pilostat. With the thermopile the millivolts produced provide the current, in series, to the gas burner control circuit. If the pilot light goes out, the circuit to the gas valve is permanently opened and cannot be reclosed until the pilot is reignited. A typical furnace electrical system is shown in figure 38.





The principle of operation for the automatic pilot is as follows:

The constant burning pilot, in addition to performing the burner lighting function, is directed so as to heat the hot junction of the thermocouple in the automatic pilot circuit. The thermocouple generates electricity which energizes an electromagnet.

The thermocouple operates on the principle that when two dissimilar metals are connected together at their respective ends and one junction or connection is maintained at a higher temperature than the other, an electrical potential and current flow is produced in the system.

A simple iron-constantan thermocouple is shown.

Figure 38.

Heating and Cooling Thermostats

All thermostats serve the same purpose; to control the temperature range of the controlled variable. The thermostat that is covered in this area of instruction is the dual-purpose, low-voltage, heating-cooling thermostat used in domestic applications.

Low-voltage thermostats operate on 24 or 26 volts depending on the current load and type transformer used. In homes, wired for 110 volts, the 24-volt thermostat is used. Newer homes, wired for 115-120 volts, provide the thermostat with 26 volts.

There are several styles of thermostats; the one most commonly used is the type which places the contactors in a sealed glass bulb containing mercury. The bulb is attached to the sensing device, normally a bimetal coil and the bulb tilts in response to the change in the controlled variable.

THERMOSTAT SUBBASE. The dual-purpose thermostat has two major components, the thermostat and the subbase. The subbase serves as a receptacle for the wiring and the cooling anticipator.

Anticipators

Since low-voltage temperature thermostats are operated solely by mechanical action, they are not too sensitive. This results in wide temperature variations in the controlled space in both the heating and cooling cycles of the system. To compensate for the mechanical action and to increase the sensitivity of the instrument, a device known as an anticipator is added to the thermostat.

THE COOLING ANTICIPATOR. The cooling anticipator appears as a fixed resistor in the thermostat subbase. The anticipation function is the reverse for the cooling cycle. The cooling anticipator is active only during the OFF cycle, and is wired in the thermostat circuit in parallel with the power source. During the OFF cycle, the points in the contactor are open, so current taking the path of least resistance will divert through the anticipator and produce a minute amount of heat which is sensed by the bimetal coil in conjunction with the rise in the room temperature. This small amount of heat causes the thermostat to react prior to the temperature in the controlled space getting too warm thus allowing the temperature differential to be within + or - 3°F.

Remember, the heating anticipator is wired in series with the control circuit, and the cooling anticipator is wired in parallel with the points of the thermostat.

HEATING ANTICIPATORS. These anticipators generate a small amount of heat inside the thermostat during the heating cycle. The bimetal element senses two heat sources; the room temperature change and the temperature change emitted by the anticipator. This causes the circuit to be broken a few moments before the room temperature is reached closing the gas valve and shutting off the burners in the furnace. Then the remaining heat in the heat exchanger is discharged into the room which raises the temperature to the set point. When the thermostat calls for heat, the gas valve will again open and the burner will ignite repeating the cycle until enough heat is produced to satisfy the thermostat. With the incorporation of the anticipator, the undesirable condition of wide temperature variations between cycles is eliminated. The anticipator can contain the room temperature to + or - 3°F differential.

Heat anticipators are normally adjustable. Adjustment is generally accomplished by placing the wiper arm at the correct resistance value. If you know the current draw of the gas valve, set the wiper arm at that point. If the current draw is unknown, use a very sensitive ammeter and determine the amperage draw. If the anticipator has to be adjusted by trial and error, move the arm one direction; and if short cycling occurs, move it in the other direction a little at a time until satisfactory results are obtained.

Current Flow on the Heating Cycle

When heating is desired the heat/cool switch on the thermostat is in the heat position and the fan switch on the thermostat is in the AUTO position. Using the diagram in figure 39, let's trace the flow of current. Current flows from the left side of the transformer to R on the thermostat. No current will flow to O because the switch is on heat. Current then flows to terminal 2, to terminal 4 and through the heat anticipator. From the heat anticipator, current flows to the mercury bulb. If the thermostat is calling for heating, the bulb will be in the position as shown in figure 39 and current will flow through it to terminal 5 on to terminal 1. It then flows through the switch to terminal W to the gas valve, pilot, and limit switch and returns to the right side of the transformer.

Current Flow to the Fan

The heat/cool switch and the fan selector switch takes the coil on the fan relay out of the circuit so the fan operates on the upper contacts of the fan relay. Current flows from line to terminal 4 on the relay through the upper contact points to terminal 5 on the relay through the fan switch to the motor and returns to line. The fan switch cycles the fan.

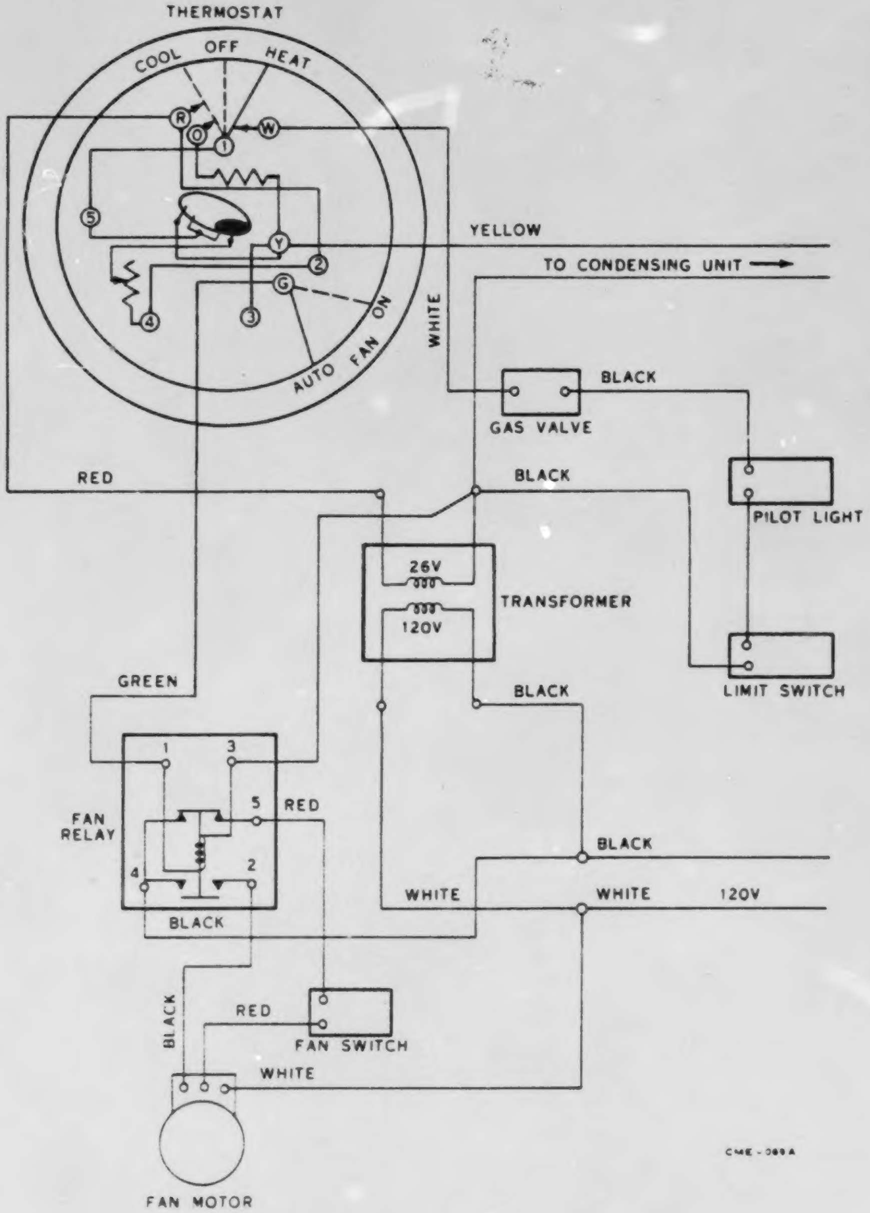

THERMOSTAT
COOL
OFF
HEAT
R
O
I
W
5
Y
2
G
4
3
AUTO
FAN
ON
YELLOW
TO CONDENSING UNIT
WHITE
BLACK
GAS VALVE
RED
BLACK
PILOT LIGHT
26V
120V
TRANSFORMER
GREEN
BLACK
LIMIT SWITCH
1
3
5
RED
FAN RELAY
4
2
BLACK
BLACK
WHITE
WHITE
120V
BLACK
RED
FAN SWITCH
WHITE
FAN MOTOR

Figure 39. Furnace Wiring Diagram

Terminal Designations

Manufacturers of control panels have terminal designations by code letter to facilitate the system hookup of external devices and to troubleshoot the entire system of the residential heating/cooling unit from a central location.

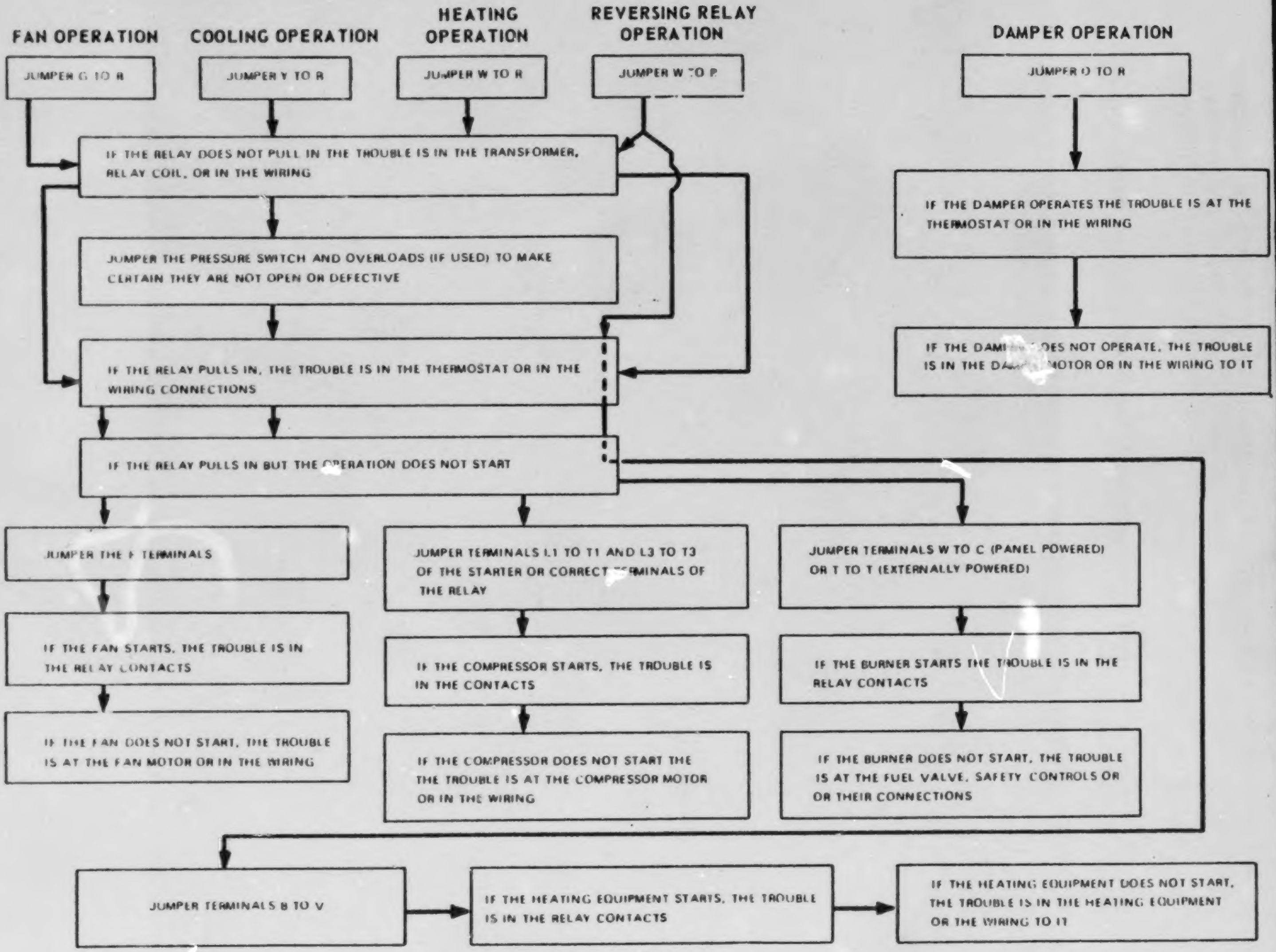
The control panel is the nerve center and connection box for the heating/cooling system. These panels are usually centrally located and the terminal arrangement is designed so certain terminals may be used for isolating various parts and to simplify troubleshooting the entire system.

The terminal designations listed below are the common ones used by various manufacturers and should be memorized.

V or R	--	Hot switched leg of 24-volt power, used on heating and cooling thermostats or heating/cooling thermostats with common power.
H or W	--	Heating single-stage only, cycles with bimetal switch.
C or Y	--	Cooling single-stage only, cycles with bimetal switch.
F or G	--	Fan circuit.
Z or B	--	Constant energization through manual switch when in HEAT position.
D or O	--	Constant energization through manual switch when in COOL position.
M or R	--	Isolated power terminals for heating circuit, used on heating/cooling thermostats with isolated circuits, jumper when used with common power.
V or RC	--	Isolated power circuit for cooling circuit, used on heating/cooling thermostats with isolated circuits, jumper supplied.
H1 or W1	--	First stage of two stage units. (Heating)
H2 or W2	--	Second stage of two stage units. (Heating)
C1 or Y1	--	First stage of two stage units. (Cooling)
C2 or Y2	--	Second stage of two stage units. (Cooling)
L or X	--	Warning light, dirty filter, electronic heat, etc.

These designations are the best tools to spot a system, panel, or component malfunction or failure by using a jumper wire across the correct terminals.

The condensed troubleshooting chart, figure 40 and the illustrations that follow show the terminal connections for each part of the panel circuits and the method for troubleshooting that part.


FAN OPERATION
COOLING OPERATION
HEATING OPERATION
REVERSING RELAY OPERATION
DAMPER OPERATION
JUMPER G TO R
JUMPER Y TO R
JUMPER W TO R
JUMPER W TO R
JUMPER O TO R

IF THE RELAY DOES NOT PULL IN THE TROUBLE IS IN THE TRANSFORMER, RELAY COIL, OR IN THE WIRING

JUMPER THE PRESSURE SWITCH AND OVERLOADS (IF USED) TO MAKE CERTAIN THEY ARE NOT OPEN OR DEFECTIVE

IF THE RELAY PULLS IN, THE TROUBLE IS IN THE THERMOSTAT OR IN THE WIRING CONNECTIONS

IF THE RELAY PULLS IN BUT THE OPERATION DOES NOT START

JUMPER THE F TERMINALS

IF THE FAN STARTS, THE TROUBLE IS IN THE RELAY CONTACTS

IF THE FAN DOES NOT START, THE TROUBLE IS AT THE FAN MOTOR OR IN THE WIRING

JUMPER TERMINALS L1 TO T1 AND L3 TO T3 OF THE STARTER OR CORRECT TERMINALS OF THE RELAY

IF THE COMPRESSOR STARTS, THE TROUBLE IS IN THE CONTACTS

IF THE COMPRESSOR DOES NOT START THE THE TROUBLE IS AT THE COMPRESSOR MOTOR OR IN THE WIRING

JUMPER TERMINALS W TO C (PANEL POWERED) OR T TO T (EXTERNALLY POWERED)

IF THE BURNER STARTS THE TROUBLE IS IN THE RELAY CONTACTS

IF THE BURNER DOES NOT START, THE TROUBLE IS AT THE FUEL VALVE, SAFETY CONTROLS OR OR THEIR CONNECTIONS

IF THE DAMPER OPERATES THE TROUBLE IS AT THE THERMOSTAT OR IN THE WIRING

IF THE DAMPER DOES NOT OPERATE, THE TROUBLE IS IN THE DAMPER MOTOR OR IN THE WIRING TO IT

JUMPER TERMINALS B TO V

IF THE HEATING EQUIPMENT STARTS, THE TROUBLE IS IN THE RELAY CONTACTS

IF THE HEATING EQUIPMENT DOES NOT START, THE TROUBLE IS IN THE HEATING EQUIPMENT OR THE WIRING TO IT

Figure 40.

Power Circuit

When a voltmeter or test lamp is the electrical test instrument which is available to you, you must then perform your electrical test on a live circuit. The voltmeter range or scale and the test lamp voltage rating must be equal to or higher than the circuit voltage being tested. If you are using a multimeter, be sure that it is not in the OHMS position as it will cause damage to the meter movement.

Figures 41 and 42 are typical electrical power connections for low-voltage transformers used in residential heating and cooling systems. Test points and troubleshooting approaches will be discussed in reference to figures 41, 42, and others that will follow.

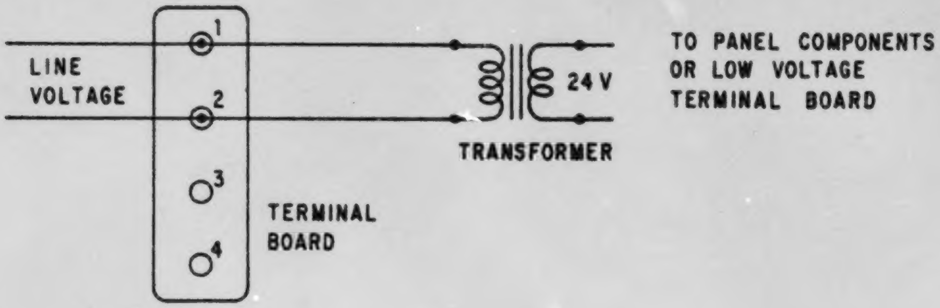

LINE
VOLTAGE
1
2
3
4
TERMINAL
BOARD
24 V
TRANSFORMER
TO PANEL COMPONENTS
OR LOW VOLTAGE
TERMINAL BOARD

Figure 41.

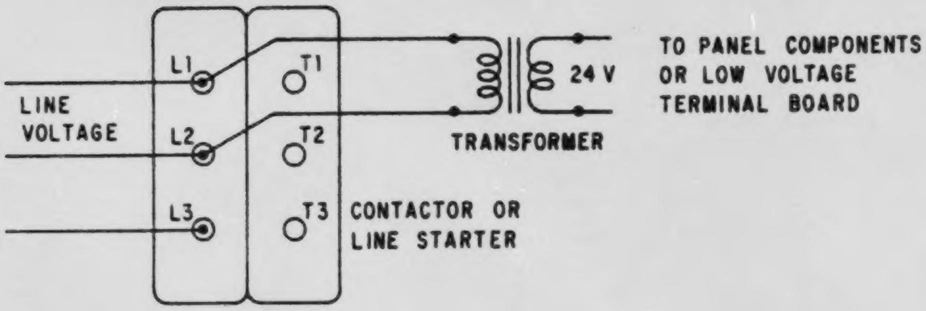

LINE
VOLTAGE
L1
L2
L3
T1
T2
T3
CONTACTOR OR
LINE STARTER
24 V
TRANSFORMER
TO PANEL COMPONENTS
OR LOW VOLTAGE
TERMINAL BOARD

Figure 42.

TRANSFORMER POWER TEST. A test lamp or voltmeter will determine if the primary coil of the transformer is being supplied with voltage but will not indicate that the primary coil is actually consuming power. An ammeter, either in series or of the clamp-on type, or a test lamp wired in series with the primary, will confirm that power is being consumed by the transformer. Voltage at the secondary of the transformer assures us that the primary coil has voltage and current is flowing in it. The current flow in the primary will be at its lowest when the secondary is open circuited.

The test points will be at a terminal board or at the line connections of the contactor or line starter. Even if voltage is indicated at the test points, it may not be able to reach the transformer because of an open in one of the power leads. A test for current flow will determine if an open does exist in the primary side of the transformer. Without an ohmmeter, the circuit must be tested for current flow in order to determine if the coil is open. Zero output from the secondary, with voltage available to the transformer, is usually a good reason to change the transformer.

With the test lamp or voltmeter leads connected between the transformer power wires at the terminal board or contactor, the light will light and the voltmeter will read volts if the voltage is present at the test points. If the lamp or voltmeter does not indicate voltage, check the fuses and wiring ahead of the test points. The transformer power wiring is shown in figure 41 and 42. The test points in figure 41 are terminals 1 and 2. The test points in figure 42 are terminals L1 and L2.

Figure 43 illustrates the connecting arrangement for the test leads for both the voltmeter and the test lamp. Only one instrument will be shown. A quick check for voltage on the secondary side will often save you time because if voltage is present on the secondary, the primary must be functioning.

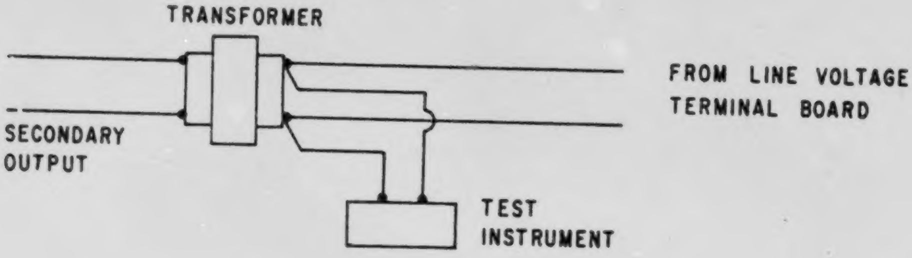


Figure 43.

Transformer Low-voltage Circuit

Low-voltage transformers often have connecting terminals directly on them and are therefore easy to test for voltage output. Sometimes the secondary voltage is available for testing and usage only at a terminal board. Figure 44 illustrates the test instrument connections for checking the transformer output voltage, at the transformer, with open circuit conditions. This test is valuable because it isolates the transformer being tested from any other transformer that may be paralleled to it. The open circuit voltage may be good; however the closed circuit voltage may be too low when power is actually being consumed by the circuit devices. Too much load on the secondary side of the transformer will usually cause the voltage to be low; therefore, a closed circuit voltage test is also valuable. If the test lamp glows or the meter reads, power is available; if not, the primary side of the transformer is not functioning. The cause may be an open in the primary power wires or in the transformer coil itself.

> NOTE: When testing a low voltage control circuit with a voltmeter or test lamp, such as when you trace voltage availability through the circuit, you must remember that the low-voltage control circuit is isolated from the chassis of the machine and the neutral buss terminals, if a neutral exists. Voltage reading will only occur when test leads are connected to wires and terminals physically connected to the transformer output.

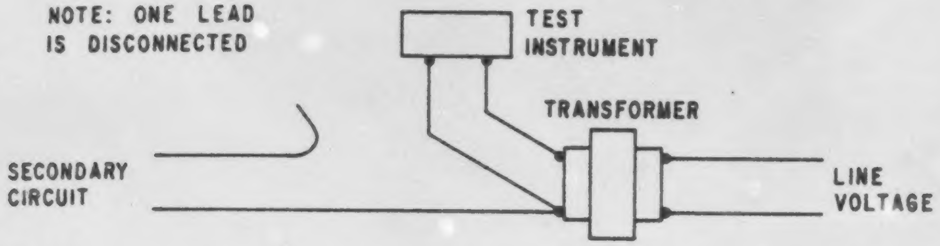

NOTE: ONE LEAD
IS DISCONNECTED
TEST
INSTRUMENT
TRANSFORMER
SECONDARY
CIRCUIT
LINE
VOLTAGE

Figure 44.

Relay Coil Circuit Test

Testing the voltage at the relay terminals is the same thing as testing the output terminals of the transformer; but, by testing at the relay itself, we have eliminated the guesswork about the wires not carrying the voltage to the relay. If voltage is available at the relay, as would be indicated by the test lamp glowing or the voltmeter reading we can then assume the secondary circuit is good up to the relay. Now, if the relay does not operate, the cause will probably be an open in the relay coil itself or a mechanical malfunction of the moving parts of the relay. If current does flow through the coil, the problem must be mechanical. Figure 45 shows the test instrument connections that will check the voltage available to the coil of the relay. Figure 46 shows a method of using a test lamp to confirm that current is flowing through the coil; therefore, the coil is probably good and a mechanical disorder is present in the relay, if current is flowing through the relay. The test lamp bulb will glow if the coil has continuity and current is flowing through it.

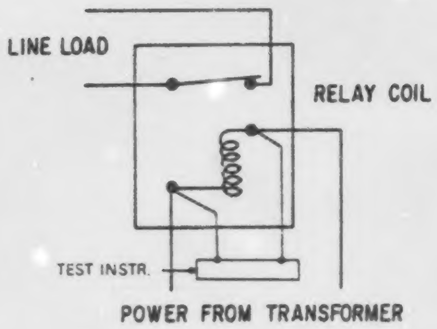

LINE LOAD
RELAY COIL
TEST INSTR.
POWER FROM TRANSFORMER

Figure 45.

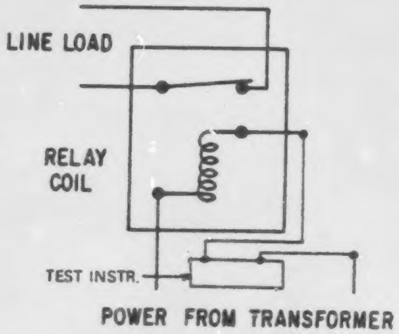

LINE LOAD
RELAY
COIL
TEST INSTR.
POWER FROM TRANSFORMER

Figure 46.

Cooling Circuit

Figure 47 illustrates the circuits involved in controlling a single-phase compressor with a contactor. The operation of the contactor is controlled by a low-voltage control circuit which includes a dual-pressure motor control, thermal overload relay contacts, and an indoor thermostat as functional controls. The contactor is actuated by an operating coil in response to the control circuit. The use, of an overload relay which senses the current flow of the motor, offers current overload protection which will open the control circuit and stop the compressor in the event of overload conditions. If the overload protection were built into the contactor, the contactor would then be classified as a line starter. The operation of the overload relay is the same for the line starter as it is for a separate relay used with a contactor. The heater of the overload relay is in series with the motor load wire while the thermal contacts of the relay is in series with the control circuit.

OPERATION. Figure 47 shows that the thermostat contacts are in the OPEN position; therefore, the compressor contactor will not be closed because the operating coil is deenergized. When the thermostat contacts do close, the contactor will start the compressor, provided that the control circuit safety devices are all closed.

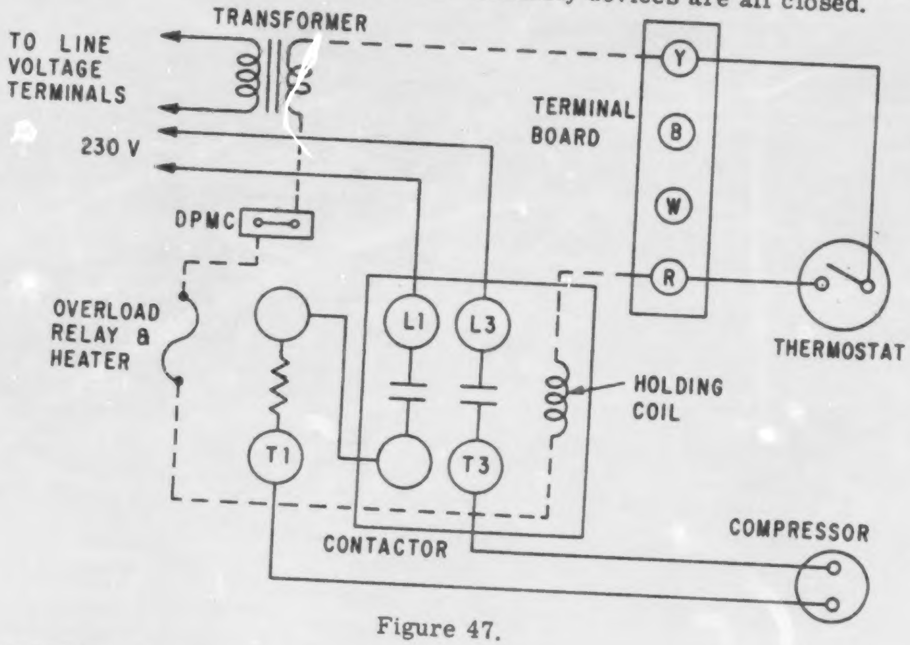


Figure 47.

TROUBLESHOOTING. Start troubleshooting by bypassing the indoor thermostat with a jumper wire. If the compressor does not start, check the control circuit safety devices for opens. Some units depend on the compressor safety devices being closed before the control transformer can be powered. Check for control voltage availability. If control voltage is present, start jumpering the other safety devices in the control circuit until the contactor energizes. If the compressor runs as a result of the jumper test, you have found the disorder. If the contactor does actuate, but the compressor fails to run, the contacts of the contactor are burned or mechanically stuck open. It is also possible that the line voltage may not be available to the contactor line terminals. If line voltage is available, it may be necessary to manually close or jumper the contacts of the contactor to check the compressor electrically.

Fan Circuit

The typical fan circuit shown in figure 48 is shown in the deenergized position. The fan relay is energized on a call from the thermostat or if the fan switch is in the ON position. The fan switch may also be energized through the starter or contactor. When two-speed fan motors are used, the low speed is controlled by the plenum switch and operates on the heating cycle; the high speed is controlled by the fan relay and operates on the cooling cycle.

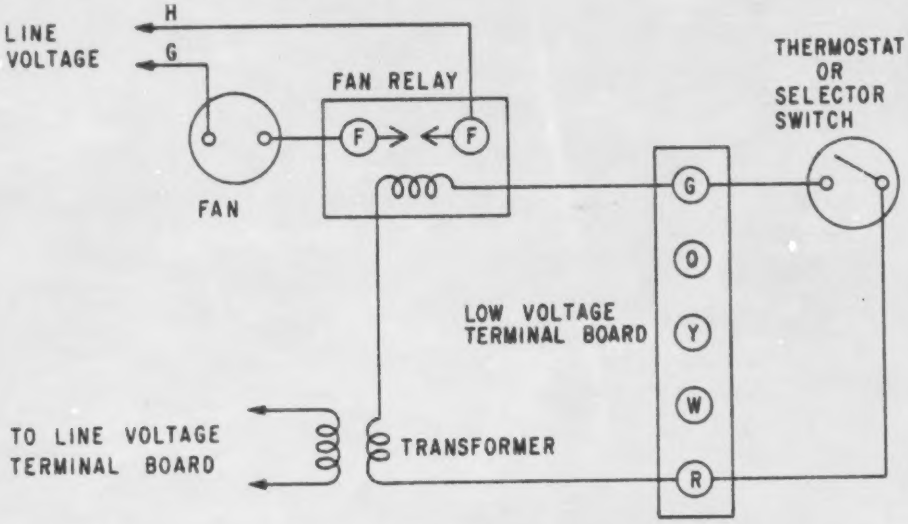


Figure 48.

To troubleshoot the fan circuit jumper terminal G to R which bypasses the external control circuit. If the relay does not pull in, the trouble is in the relay coil. If the relay pulls in and the fan starts, the trouble is in the external control circuit. Check the external control circuit to determine the defective component and repair or replace it. If the relay pulls in but the fan does not operate, jumper the F terminals.

CAUTION: These terminals are line voltage.

If the fan starts, the trouble is in the relay contacts and the relay must be replaced. If the fan does not start, the trouble is in the fan motor or the wiring to it. Check for open circuits in the motor or wiring.

Damper Circuit

The simple damper circuit shown in figure 49 is typical of the type used with heating/cooling systems. The damper motor is connected to the C and O terminals or the Y terminal in the panel. The ON cycle of the damper motor is controlled by the thermostat or selector switch.

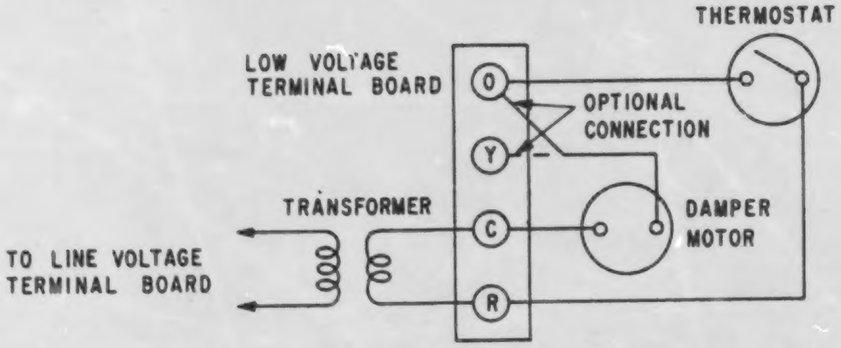


Figure 49.

To troubleshoot the damper motor circuit, jumper terminal O to R which bypasses the external control circuit. If the motor operates, the trouble is in the external control circuit. Check for open circuits or control defects. If the damper does not operate, the trouble is in the damper motor or the circuit to it. Check for open circuits in the wiring or the damper motor and repair or replace.

Reversing Relay Circuit

The reversing relay has two sets of contacts forming an interlock to prevent the cooling system from operating when the selection switch is set for heating and also prevents the heating system from operating when the selection switch is set for cooling. The thermostat bimetal operates the reversing relay to make and break the relay contacts. The IR1 (heating) contacts make when the external control actuates the relay coil. When the relay is deenergized, the IR2 (cooling) contacts are made. The cooling system is energized from the O terminal which is energized from the B terminal which is energized on heating. (See Figure 50.)

To troubleshoot the reversing relay circuit jumper terminals W to R which bypass the external control circuit. If the relay does not pull in, the trouble is in the relay coil. If the wiring is not broken, the coil is defective and must be replaced. If the relay pulls in, the trouble is in the external control circuit, check for an open circuit in the wiring or controls and repair or replace. If the relay pulls in, but the heating equipment does not operate, jumper terminals B and V, if the heating equipment starts, the trouble is in the relay contacts and the entire relay must be replaced. If the heating equipment does not start, the trouble is in the heating equipment or the wiring to it.

When troubleshooting the cooling circuit contacts of the relay IR2, jumper terminals O and Y. These contacts will only be made when the relay is deenergized.

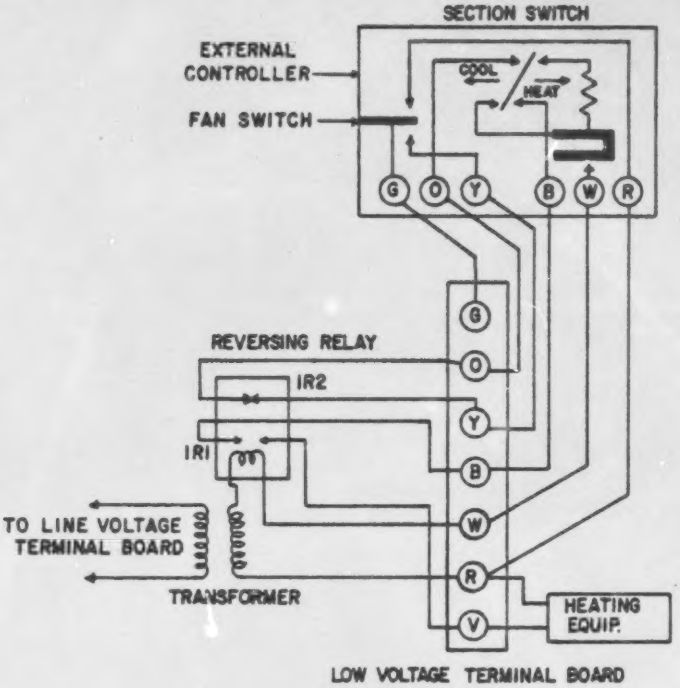

SECTION SWITCH
EXTERNAL CONTROLLER
FAN SWITCH
COOL
HEAT
G
O
Y
B
W
R
REVERSING RELAY
IR2
IR1
TO LINE VOLTAGE TERMINAL BOARD
TRANSFORMER
G
O
Y
B
W
R
V
HEATING EQUIP.
LOW VOLTAGE TERMINAL BOARD

Figure 50.

Heating Circuits

The circuits shown in figures 51 and 52 show the heating relay deenergized. When the thermostat calls for heat, the relay makes contact and energizes the panel-powered or externally-powered heating equipment

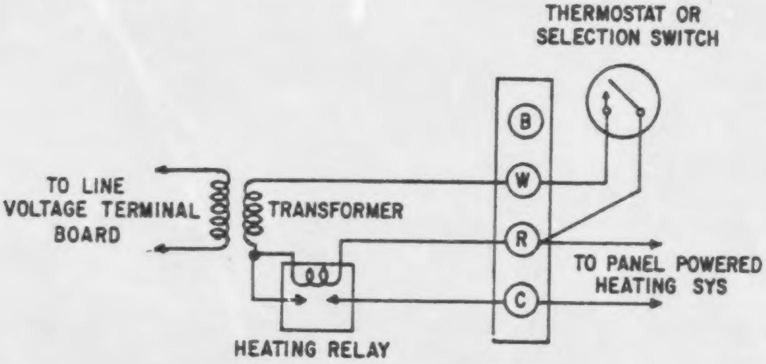

THERMOSTAT OR SELECTION SWITCH
B
W
R
C
TO LINE VOLTAGE TERMINAL BOARD
TRANSFORMER
TO PANEL POWERED HEATING SYS
HEATING RELAY

Figure 51.

Some panels may operate the system directly from the thermostat using the W and R terminals only for connections.

To troubleshoot the heating system, refer to figure 52, jumper terminals W and R which bypass the external control system. If the relay does not pull in, the trouble is in the relay coil and it should be replaced. If the relay pulls in and the burner starts, the trouble is at an external control or its wiring. If the relay pulls in but the burner does not start, jumper terminals W to C (panel-powered) or T to T (externally-powered). If the burner starts, the trouble is in the relay contacts and the relay should be replaced. If the burner does not start, the trouble is at the heating system or in the wiring connections.

The panel R terminal always acts as the transformer power supply. When a selection switch is used, the panel B terminal is connected to the selection switch B terminal.

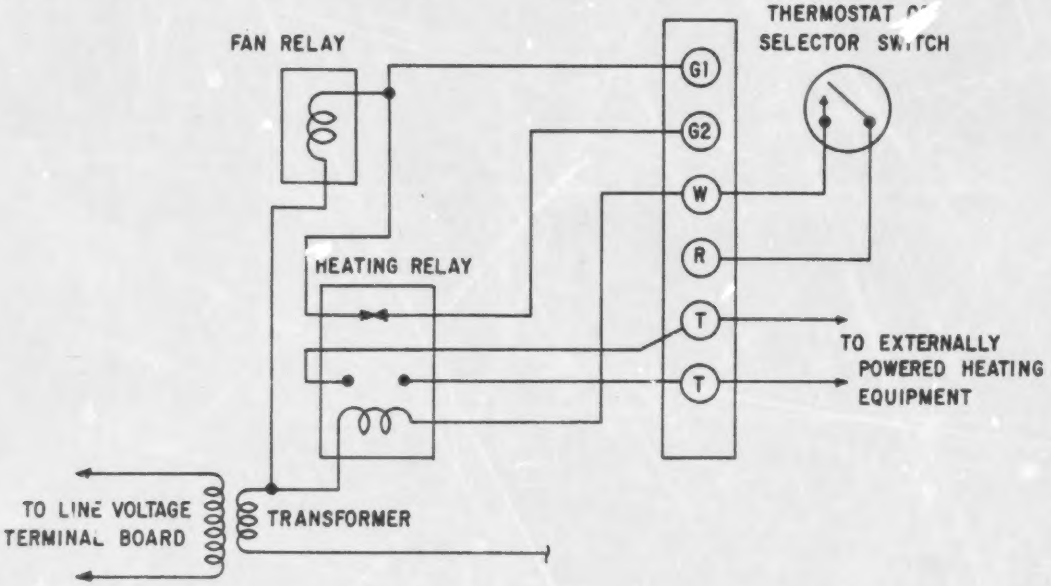


Figure 52.

Impedance (Lockout) Relay Circuit

The impedance relay has SPST switching and a high impedance coil. This coil is in series with the contactor coil. A shunt circuit around the impedance coil is provided through a normally-closed impedance relay contact, automatic reset overload, and automatic reset high and low pressure cutout. See figure 53.

The contactor coil can then be energized through the cooling contacts of the thermostat. If the overloads or the DPMC should break their contacts, the shunt circuit is broken and the impedance relay will pull in opening the contacts. The resistance of the impedance relay is so high that an insufficient voltage is in the contactor to hold its contacts. After the overload or pressure control cutouts have remade, the circuit must be reset by interrupting the power through the impedance relay. Moving the system switch from cool to reset or off and back to cool deenergizes the relay and makes the contact. This completes the original circuit and will furnish cooling under a demand from the thermostat.

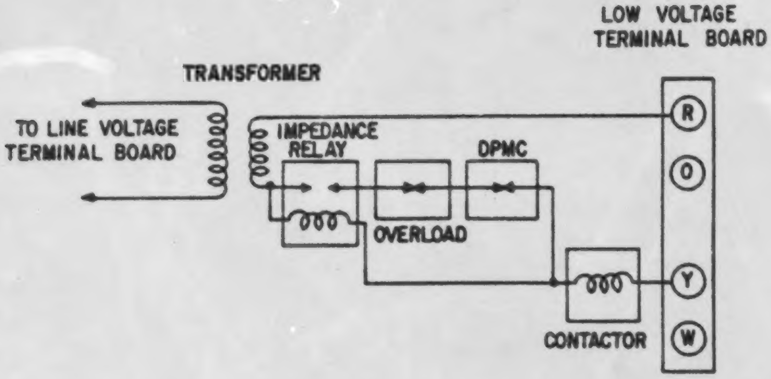


Figure 53.

To troubleshoot the impedance relay circuit, jumper terminals R to Y which bypasses the external control circuit. If the contactor makes, the trouble is in the external control circuit. If the contactor does not make, jumper the overload, high- and low-pressure cutouts contacts and the relay contacts. If the contactor pulls in, the trouble is in one or more sets of contacts. Remove the jumper from the overload. If the contactor drops out, the overload is defective. If the overload is not open, remove the jumpers from the high-low pressure switches one at a time. If the contactor drops out, the control is defective and must be replaced. If both overload and high-low pressure contacts are not open, remove the jumper from the relay contacts. If the relay drops out, the contacts are defective and the entire relay must be replaced. If the unit short cycles, the impedance relay coil is not breaking the relay contacts when the overload or high-low pressure cut-outs open the circuit. Check for a loose connection or burnt coil.

SUMMARY

The information presented in this unit of instruction should prove valuable to you if you should ever encounter residential heating/cooling systems in the course of your duties. The information has included the major components, electrical systems, and troubleshooting of control systems found with these units.

REFERENCES

Modern Refrigeration and Air Conditioning, Althouse and Turnquist

Principles of Refrigeration, Dossat

SG 3AZR54550-2-III-3
September 1974

CENTRIFUGAL AIR-CONDITIONING SYSTEMS

OBJECTIVES

This study guide will aid you in learning the principles of an indirect expansion cooling system. The centrifugal means of compressing and circulating the primary refrigerant to cool the secondary refrigerant will be discussed thoroughly in this study guide.

INTRODUCTION

Centrifugal compression machines are used to cool large buildings because of their compactness and high capacity for a given physical size. This type of compression and low operating pressures go hand in hand. The refrigerant used in the centrifugal machine is what allows the low operating pressures and the much smaller tendency toward refrigerant leakage.

DEFINITIONS

Direct Expansion

In previous units of instruction many applications of air-conditioning systems have been discussed. These applications have been numerous, but all have been of the "direct expansion " type. Just what do we mean when we say "direct expansion"? In the dictionary we find "direct"means an unbroken connection or a straight bearing of one upon another; "expansion" relates to the act or process of expanding in size or volume. You can see by referring to figure 54 that a direct expansion system for cooling is one, where the controlled variable comes in direct contact with a single refrigerant source, thereby causing the refrigerant to expand or boil, hence the removal of heat directly.

The centrifugal and absorption systems differ in that they use a secondary refrigerant--water or brine--to cool the variable. Refer to figure 55. The heat from the conditioned space is absorbed by the secondary refrigerant. The secondary refrigerant's heat is then absorbed by the primary refrigerant. The heat that originated in the conditioned space is eventually given back to the outside air by the machine's condenser or cooling tower. Thus these machines are called "indirect" expansion chillers.

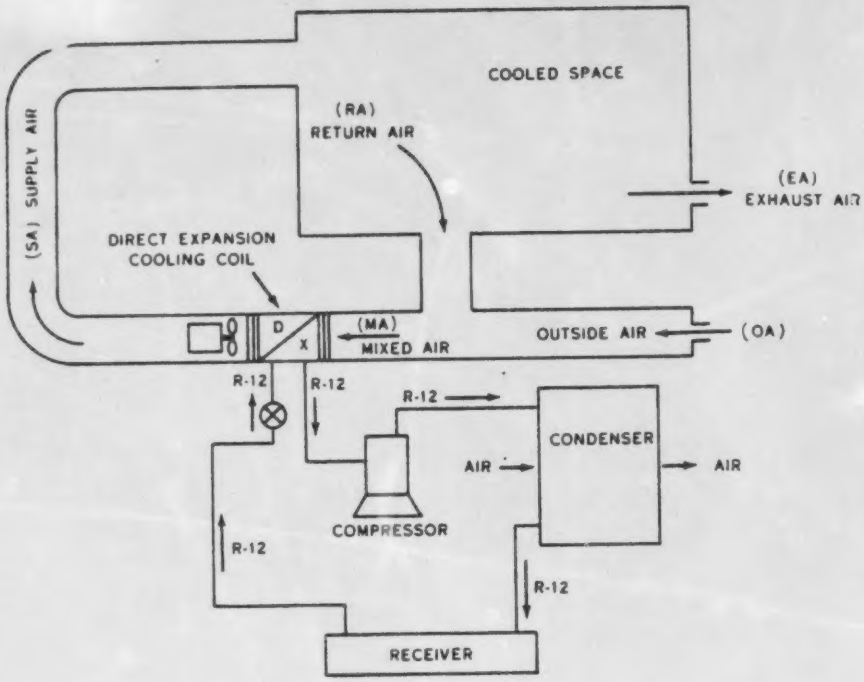

COOLED SPACE
(RA)
RETURN AIR
(EA)
EXHAUST AIR
(SA) SUPPLY AIR
DIRECT EXPANSION
COOLING COIL
D
X
(MA)
MIXED AIR
OUTSIDE AIR
(OA)
R-12
R-12
R-12
CONDENSER
AIR
AIR
COMPRESSOR
R-12
R-12
RECEIVER

Figure 54. Direct Expansion System

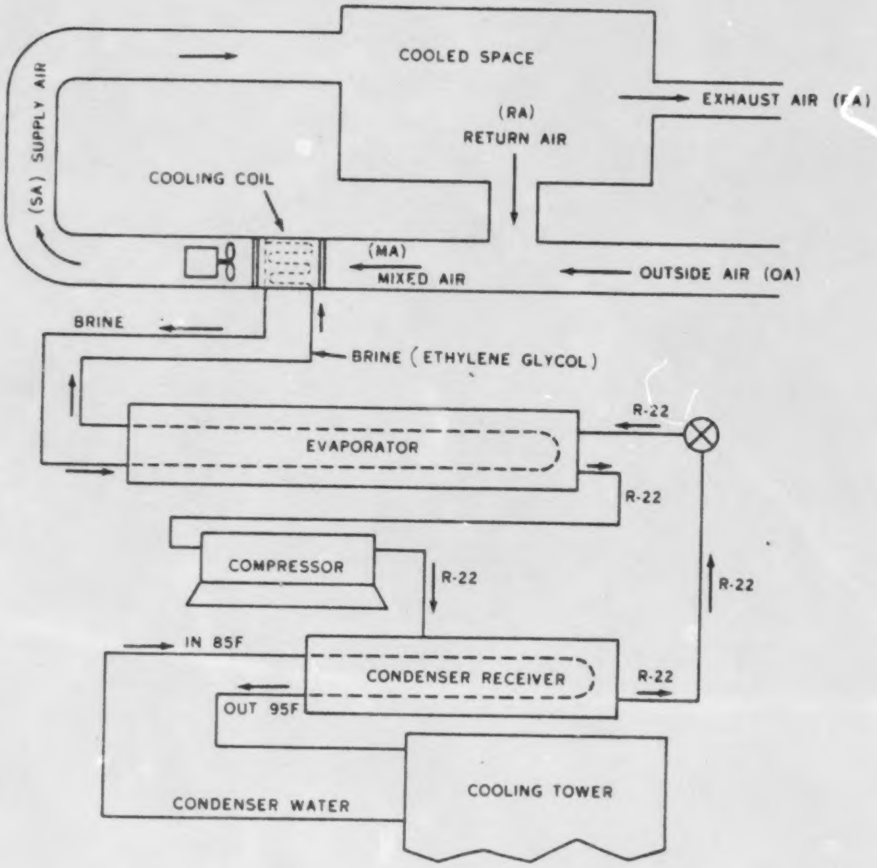

COOLED SPACE
EXHAUST AIR (EA)
(RA)
RETURN AIR
(SA) SUPPLY AIR
COOLING COIL
(MA)
MIXED AIR
OUTSIDE AIR (OA)
BRINE
BRINE (ETHYLENE GLYCOL)
R-22
EVAPORATOR
R-22
COMPRESSOR
R-22
R-22
IN 85F
CONDENSER RECEIVER
R-22
OUT 95F
COOLING TOWER
CONDENSER WATER

Figure 55. Indirect Expansion System

Centrifugal Refrigeration

In previous units of instruction, all compressors that were discussed were of the positive-displacement type. Vapor is drawn into a cylinder where a piston compresses the vapor thus reducing the volume. After compression, the vapor is forced from the cylinder by further decreasing the volume of the cylinder to zero or nearly zero. These are termed positive-displacement compressors and can build up a pressure that is limited only by the volumetric efficiency and the strength of the parts to hold this pressure. Centrifugal refrigeration is a type where the compressor depends entirely on the centrifugal force of a high-speed wheel to compress the vapor flowing through the wheel. There is no positive displacement; this action is called "dynamic" compression. The compressor is fundamentally a centrifugal blower designed for high-speed operation at a higher discharge pressure than most blowers operate, 15 to 20 psi difference between the suction and discharge. The pressure a centrifugal compressor can develop depends on the tip speed of the wheel. Tip speed is based on the diameter of the wheel and its revolutions per minute. The capacity of the compressor is determined by the size of the passages through the wheel.

CHARACTERISTICS AND OPERATION

Because of its high-speed operation, the centrifugal machine is fundamentally a high volume, low-pressure machine. Such a machine has been built as small as 50-ton capacity, but is only competitive with other types of compressors in a range above 100 tons. Centrifugal compressors of over 3000-ton capacity are now being built.

Because of its low-pressure characteristics, the centrifugal compressor works best with a low-pressure refrigerant. Low-pressure refrigerants are those fluids that require only small increases in pressure to cause condensation of the refrigerant vapor. The low-pressure refrigerants also have other characteristics which suit the centrifugal machine well. Refrigerants with high liquid density produce a large amount of vapor per pound of liquid. The high vapor volume is ideal for use with a centrifugal compressor. The stable operation of a centrifugal compressor depends on a sufficiently large volume of vapor through the impeller. When the required tonnage is high, it requires a very large bulky compressor, so a refrigerant with a lower specific volume will probably be used.

The refrigerants normally used in centrifugals are R-11 and R-113. These refrigerants possess the large specific volume needed. With these refrigerants the suction pressure will be from 18 to 25 inches of vacuum depending on the evaporator temperature required. Discharge presssure will be near atmospheric. A single-stage impeller can be used with these refrigerants for air-conditioning temperatures. A two-stage impeller wheel is common for standard ton conditions. In two-stage operation, the suction of the first-stage wheel goes to the suction of the second wheel. Each stage can build up a compression ratio of about 4 to 1.

Centrifugal compresssors have been built for high-pressure refrigerants such as R-12. Refrigerant 12 has a much lower specific volume than either refrigerant 11 or 113, but works well in low temperature or very large tonnage systems. Even though refrigerants 11 or 113 remove more heat per pound than refrigerant 12, the high volume of vapor pumped by the compressor causes more refrigerant circulation and therefore more tonnage. The drawback here is that these machines may require at least five stages of compression.

Basic Centrifugal Refrigeration Cycle

The basic refrigeration cycle for a centrifugal machine is as follows. The compressor maintains the refrigerant at a low pressure in the cooler and at a higher pressure in the condenser. In the cooler the liquid refrigerant is boiled by picking up heat from the water or brine which passes through the tubes. The latent heat of vaporization necessary to boil the refrigerant is taken from the water as sensible heat which cools the water. The compressor takes its suction from the cooler, increases the pressure and temperature of the gaseous refrigerant and discharges it into the condenser. In the condenser the gas is condensed by giving up its latent heat of vaporization to the condenser water which passes through the tubes. The liquid refrigerant is then returned to the cooler through the pressure reducing (metering) device and the cycle is repeated. With these facts in mind, we can easily understand the centrifugal cycle.

The flow of refrigerant through the centrifugal machine can be seen by discussing the cycle through each of the major components, cooler, compressor, condenser, and metering device. As the cycle is discussed, typical pressures and temperatures of R-11 as an example, will be given to clarify the explanation.

Refer to figure 56. The refrigerant is entering the cooler in a liquid state. The pressure inside the cooler shell is maintained by the compressor suction which, the R-11 may be 16.9" Hg vacuum. At this pressure the corresponding temperature is 36°F. The chilled water is entering the cooler at approximately 55°F. It makes several passes through the cooler, depending upon its configuration, and leaves at a temperature of approximately 44°F. The chilled water being warmer than the refrigerant causes heat to transfer from the water, through the tubes to the refrigerant. Since the pressure in the cooler remains constant and the refrigerant is at a saturated liquid condition, the heat absorbed causes the refrigerant to boil. As the refrigerant continues to boil, the vapors formed flow through the eliminators to the lowest pressure point which is the compressor suction. The eliminators trap any liquid droplets which may be mixed with the vapor and prevents them from being carried into the compressor.

The vapor entering the compressor is at a saturated vapor condition and a temperature of 36°F. Although the temperature of the refrigerant has remained the same, 36°F, it has changed its state from a liquid to a gas. In other words, the heat transferred from the chilled water and absorbed by the refrigerant is the latent heat of vaporization for the refrigerant at that respective pressure. (16.9" Hg vacuum.)

The compressor shown in figure 56 is a two-stage type. As previously mentioned, it takes its suction from the cooler. As the refrigerant gas enters the first-stage impeller, it is at cooler conditions, 16.9" Hg vacuum and 36°F. As the gas passes through the impeller, its pressure, temperature, and heat content are increased. The gas leaving the first stage enters the suction of the second-stage impeller. The process of the gas through the second stage is the same as that through the first stage. The energy necessary to compress the gas (raise the pressure, temperature, and heat content) is provided by an electric motor. As the gas leaves the compressor, its pressure has increased to approximately 10.6 psig and it is at a superheated condition. In other words, its temperature is above the corresponding temperature of a saturated vapor for the respective pressure. The compreseor therefore, removes it from the cooler, increases the pressure, temperature, and heat content of the gaseous refrigerant and discharges it to the condenser.

The gaseous refrigerant enters the condenser in a superheated condition at 10.6 psi as shown in figure 56. Condensing water enters the condenser normally at 85°F and leaves at 95°F. Since the water is cooler than the refrigerant, heat is transferred from the refrigerant vapor to the water. The gaseous refrigerant is first cooled down to a saturated vapor and then gives up its latent heat of vaporization as it is condensed. The saturated temperature for the corresponding condenser pressure is 104°F. The condenser water, therefore, absorbs all this heat taking it out of the system. The total heat removed from the system equals the heat removed from the chilled water in the cooler and the heat absorbed during compression. The liquid refrigerant drains into the metering device as it condenses.

There are several types of metering devices used by various manufacturers to meet specific applications. For the sake of our discussion, the float type commonly called the "economizer" will be used. Other types will be discussed later in this unit of instruction.

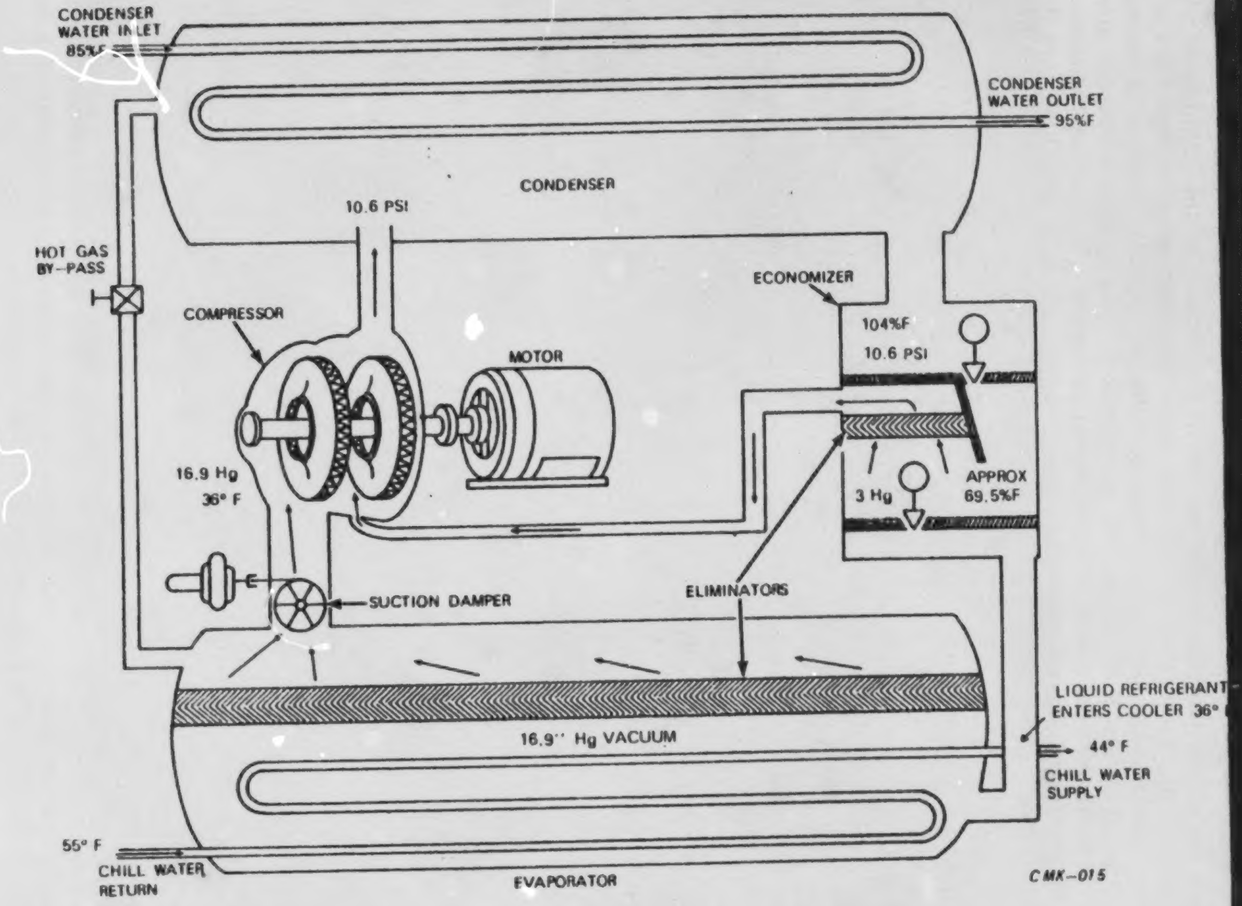

CONDENSER WATER INLET 85%F
CONDENSER WATER OUTLET 95%F
CONDENSER
10.6 PSI
HOT GAS BY-PASS
ECONOMIZER
COMPRESSOR
104%F
10.6 PSI
MOTOR
16.9 Hg
36° F
3 Hg
APPROX 69.5%F
SUCTION DAMPER
ELIMINATORS
LIQUID REFRIGERANT ENTERS COOLER 36°
16.9'' Hg VACUUM
44° F
CHILL WATER SUPPLY
55° F
CHILL WATER RETURN
EVAPORATOR
CMK-015

Figure 56. Centrifugal Machine

Figure 56, shows the economizer portion of the cycle. As the liquid level within the condenser float chamber rises, the float valve opens allowing refrigerant to flow into the economizer chamber. The pressure in the economizer chamber is maintained by the suction pressure of the second-stage impeller. This pressure is approximately half the difference between cooler and condenser pressure. Due to this reduction in pressure, a portion of the refrigerant flashes to a gas. Heat is absorbed from the remaining refrigerant as it changes from a liquid to a gaseous state. Heat is removed from the liquid refrigerant, thereby bringing it to a saturated condition at the lower pressure. The gas formed in the economizer is drawn off through an eliminator that removes any liquid droplets, and then flows to the suction side of the second-stage impeller where it mixes with the discharge gas of the first-stage impeller.

The liquid refrigerant, that remains in the economizer, collects in the economizer float chamber. Again a float valve maintains a liquid seal between the economizer and the cooler. When the level within the float chamber is sufficient to raise the float, the valve opens allowing refrigerant to flow into the cooler. Again some refrigerant will flash to gas due to the pressure reduction. This gas absorbs the heat necessary to cool the liquid refrigerant to the conditions which exist in the cooler--36°F at 16.9" Hg vacuum. This flash gas mixes with the vaporized gas as it leaves the cooler.

The economizer section serves as a pressure and temperature reducing device, and allows for gas at an intermediate condition. The economizer gives the advantage of a relatively cold liquid entering the cooler, while the gas generated to obtain this cold liquid is compressed through only one stage of the compressor, instead of two, as would be necessary if the warm liquid refrigerant passed directly from the condenser to the cooler. This results in a definite power savings: thus the term "economizer."

This complete the refrigeration cycle. Careful study of figure 56 should be made. It should be realized that this cycle is being carried out continuously under varying load conditions while the machine is in operation.

MAJOR COMPONENTS

In the discussion of the refrigeration cycle, the nomenclature, purpose, and location of the major components of centrifugal machines was mentioned; however, the manufacturers of centrifugal machines are numerous and it is beyond the scope of this study guide to discuss the different variations found in the construction of the centrifugal machines. However, a comprehensive study of one machine will be presented in the discussion, and with thoughtful study a sound working knowledge can be attained. It must be understood that before any service or maintenance is performed on a machine, the specific manufacturer's instructions should be consulted.

Coolers

Centrifugal refrigeration machines are classed as "indirect" expansion, water chillers. The cooler (evaporator) used is of the flooded type, with the tubes submerged in the liquid refrigerant and the chilled water inside the tubes. Refrigerant is evenly distributed through a perforated channel located in the bottom of the cooler.

The cooler or evaporator, see figures 57, 58, 59, is of a horizontal shell and tube construction with fixed tube sheets. The shell is low carbon steel plate rolled to shape and electrically welded in place.

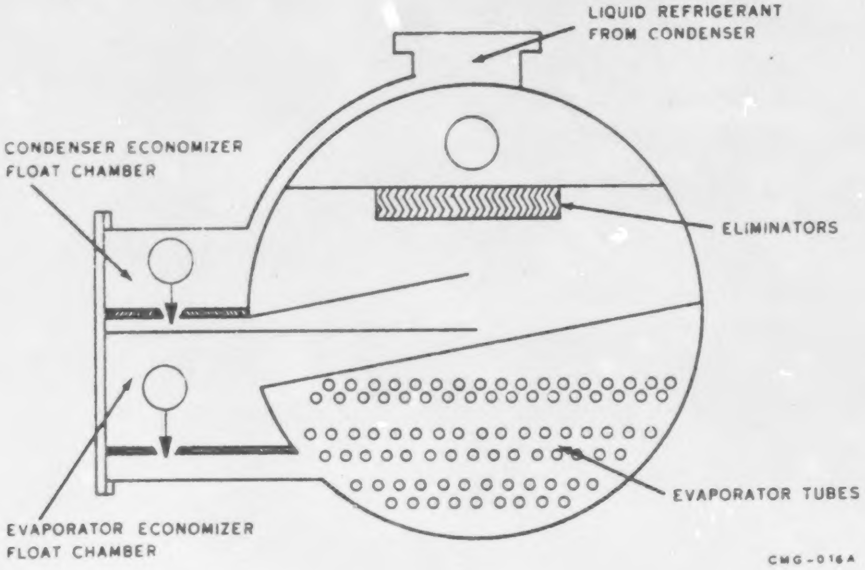

LIQUID REFRIGERANT FROM CONDENSER
CONDENSER ECONOMIZER FLOAT CHAMBER
ELIMINATORS
EVAPORATOR TUBES
EVAPORATOR ECONOMIZER FLOAT CHAMBER
CMG-016A

Figure 57. Cross Section Evaporator, with Economizer

The standard tube construction is of copper, rolled into cupro-nickel tube sheets. Cupre-nickel is an alloy which is highly resistant to corrosion. For brine or other solutions, other metals may be used. The tubes are provided with belled ends rolled into concentric grooves in the holes of the tube sheets. Tube ends are rolled into the tube sheets to give the advantage of removable tubes.

The cooler and condenser both have corrosion-resistant, cast-iron water boxes. They are designed to permit complete inspection without breaking main pipe joints. Full size separate cover plates give access to all tubes for easy cleaning. The cooler water boxes are designed for maximum 200 lbs working pressure. They are provided with cast-iron division plates to give the required number of water passes.

The flooded cooler used on centrifugal machines has no provision for superheating the refrigerant vapor. Therefore, some means must be provided to prevent droplets of liquid refrigerant from being carried over into the compressor. On some small machines, this is accomplished by providing large cross-sectional areas above the tube bundle causing low vapor velocities. This low velocity permits any droplets of liquid refrigerant to fall back into the boiling refrigerant.

Large coolers make use of multiple bend eliminator plates above the tube bundle as shown in figure 59. This perforated plate removes the liquid droplets from the vapor stream, preventing carryover into the compressor suction and assures uniform boiling of the refrigerant throughout the length of the cooler.

431

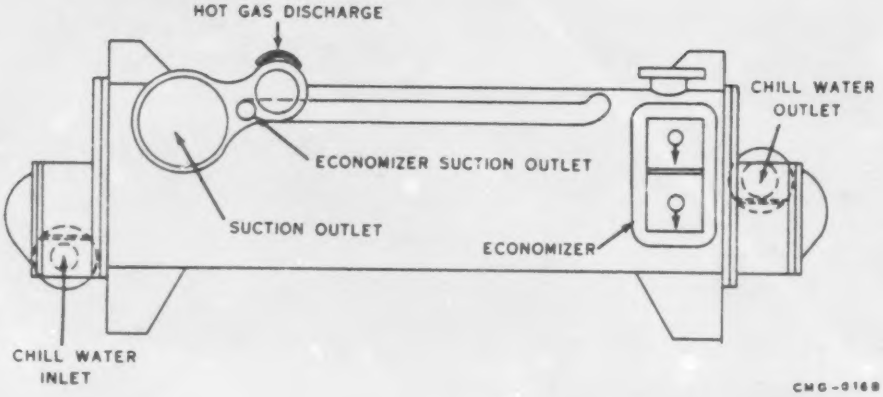

HOT GAS DISCHARGE
CHILL WATER OUTLET
ECONOMIZER SUCTION OUTLET
SUCTION OUTLET
ECONOMIZER
CHILL WATER INLET
CMG-0168

Figure 58. Evaporator Diagram

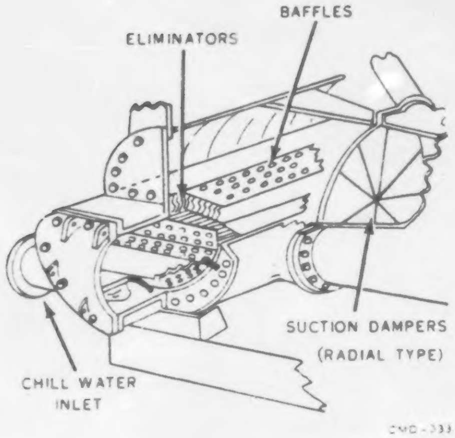

BAFFLES
ELIMINATORS
SUCTION DAMPERS (RADIAL TYPE)
CHILL WATER INLET
CMG-033

Figure 59. Cutaway Section--Suction End of Evaporator

A thermometer is provided to indicate the temperature of the refrigerant within the cooler during operation. A sight glass is provided to observe the charging and operating refrigerant level.

A charging valve is located on the side of the cooler for adding or removing refrigerant. A pipe is connected to the charging valve extending to the bottom of the cooler so that complete drainage of refrigerant is possible. A refrigerant drain to the atmosphere is also provided.

The normal refrigerant charge in the cooler covers only about 50 percent of the tube bundle. However, during operation, the violent boiling of the refrigerant usually covers the tube bundle.

A small chamber is welded to the cooler shell at a point opposite the economizer and above the tube bundle. A continuous supply of liquid from the condenser float chamber is brought to the expansion chamber while the machine is running. The bulb of the refrigerant thermometer and the refrigerant safety thermostat bulb are inserted in this expansion chamber for measuring refrigerant temperature.

A rupture valve with a 15-lb bursting disc is provided on the cooler and a 15 psig pop safety valve is screwed into a flange above the rupture disc. These items are strictly for possible disaster conditions because it is highly improbable that a pressure greater that 5 to 8 psig will ever be attained without purposely blocking off the compressor suction opening.

Condenser

The condenser is a shell-and-tube type similar in construction to the cooler. The primary function of the condenser is to receive the hot refrigerant gas from the compressor and condense it to a liquid.

A secondary function of the condenser is to collect and concentrate noncondensable gases so that they may be removed by the purge unit. The top portion of the condenser is baffled. This baffle encloses a portion of the first water pass. The noncondensable gases rise to the top portion of the condenser because they are lighter than refrigerant vapors and because it is the coolest portion of the condenser, see figures 60 and 61.

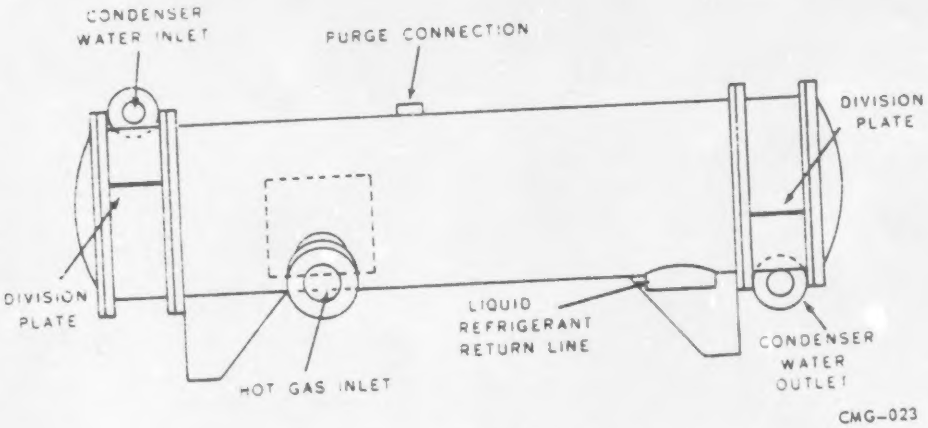


Figure 60. Condenser Diagram

A perforated baffle or distribution plate, figure 61, is installed along the tube bundle to prevent direct impact of the compressor discharge on the tubes. The baffle also serves to distribute the gas throughout the length of the condenser.

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The condensed refrigerant leaves the condenser through a bottom connection at one end and flows into the condenser economizer float chamber, see figure 60.

The water boxes, figure 60, of all condensers are designed for a maximum working pressure of 200 psig. They are provided with the necessary division plates to give the required flow. Water box covers may be removed without disturbing any refrigerant joint since the tube sheets are welded into the condenser and flanges. Vent and drain openings are provided in the water circuit.

The condenser is connected to the compressor and the cooler shells with expansion joints to allow for differences in expansion between them.

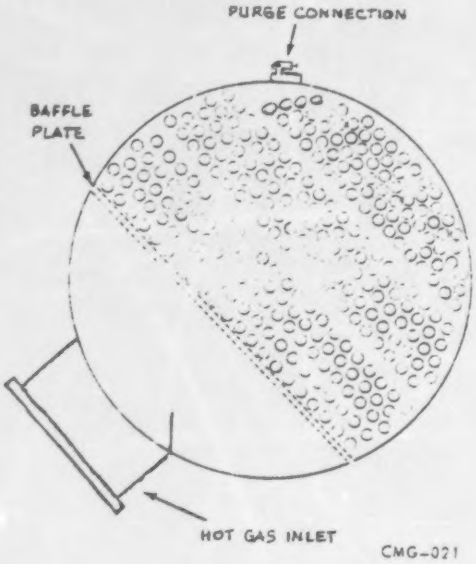

Figure 61. Cross Section of Condenser (3 Pass)

Cooler and Condenser Checkpoints

The operator must check the cooler and condenser for proper refrigerant level and make sure that the cooler and condenser are operating efficiently.

The correct refrigerant charging level is indicated by a cross wire on the sight glass. The machine must be shut down to get an accurate reading on the sight glass. For efficient operation, the refrigerant level must not be lower than 1/2 inch below the cross wire; a refrigerant level above this reference line indicates overcharge. When this condition exists the overcharged refrigerant must be removed.

If the machine has been in operation for long periods of time, the refrigerant level will drop due to refrigerant loss. When this condition exists, additional refrigerant must be added to the system to bring the refrigerant level to its proper height as indicated on the cross wire. Observe all cautions and do not overcharge the cooler.

A method of determining if the tube bundle of either the cooler or condenser is operating efficiently is to observe the relation between the change in temperature of the condenser water or chilled water and the refrigerant temperature. In most cases, the chilled water or condenser water flow is held constant. Under such conditions, the temperature change of chilled water and condenser water is a direct indication of the load. As the load increases, the temperature difference between the leaving water or condenser water entering and the refrigerant increases.

A careful check should be made of the temperature differences at full load when the machine is first operated, and a comparison made from time to time during operation. During constant operation over long periods of time, the cooler and condenser tubes may become dirty or scaled, and the temperature difference between leaving water or chilled water will increase. If the increase in temperature is approximately 2° to 3°F at full load, the tubes should be cleaned.

Read the condenser pressure gage when taking readings of the temperature difference between leaving condenser water and condensing temperature. Before taking readings, make sure the condenser is completely free of air. The purge unit should be operated for at least 24 hours before readings are taken.

Purge units used with centrifugal machines will be discussed in a later unit of instruction.

Refrigerant Metering Devices

FLOAT VALVES. Conventional expansion valves used with reciprocating equipment are not capable of handling the large volumes of refrigerant used with centrifugal machines. Float valves are used as the metering device. The unit housing these float valves is called the "economizer." It is located above the cooler tube bundle and entirely separate from the cooler gas space. Referring to figure 62, you will note on the front of the economizer is found a chamber for two float valves and the necessary passages connected lengthwise through the cooler gas space to the compressor second-stage inlet. This connection maintains a pressure in the chamber intermediate between the cooler and condenser pressures and carries away the vapor generated in the chamber. Before entering the conduit, the economizer vapor passes through an eliminator which extracts any free liquid and drains it back to the chamber. In the top is the condenser float valve which keeps the condenser drained of refrigerant and admits the refrigerant from the condenser into the economizer chamber. In the bottom is the economizer float valve which returns the refrigerant to the cooler. Without an economizer, the flash gas that occurs through the metering device enters the evaporator and imposes a load on the compressor without providing useful cooling. An economizer permits removal of flash vapors at intermediate stages, increasing the refrigerating effect of each pound of refrigerant in the evaporator, thereby reducing the power requirements at the compressor, refer to figure 62.

It should be noted that the economizer is only one method of metering the refrigerant flow in centrifugal machines. Various manufacturers use different methods. A few as follows:

Refrigerant Liquid Flow Control. In this method positive control of the liquid refrigerant between the condenser sump and cooler is provided by an electric float switch operating in conjunction with a liquid line valve operated by an electric motor. Refer to figure 63.

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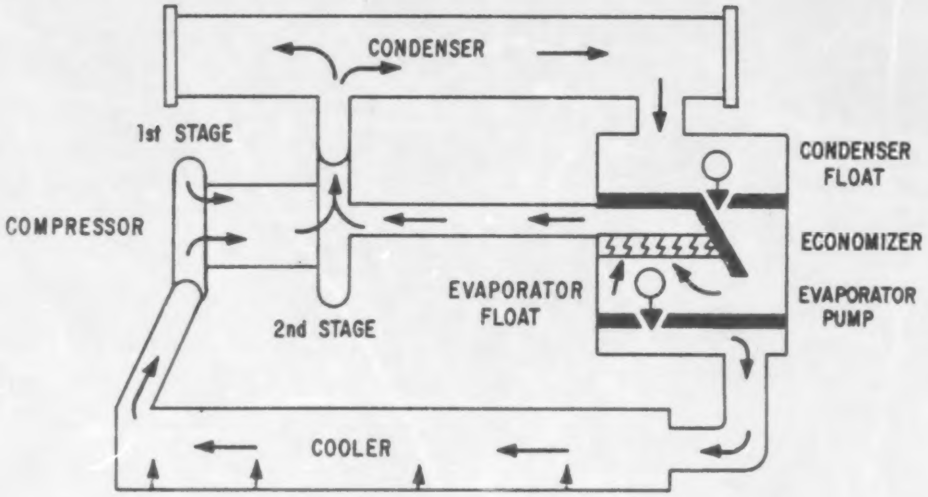
CONDENSER
1st STAGE
CONDENSER FLOAT
COMPRESSOR
ECONOMIZER
EVAPORATOR FLOAT
2nd STAGE
EVAPORATOR PUMP
COOLER

Figure 62. Operation of the Economizer

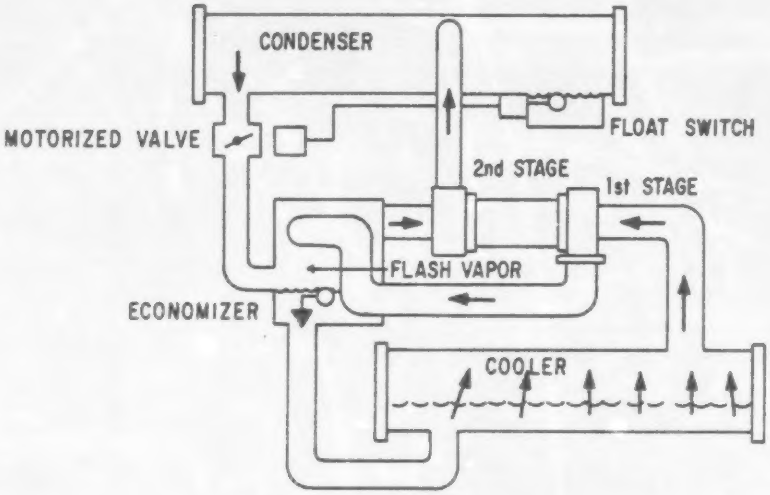
CONDENSER
MOTORIZED VALVE
FLOAT SWITCH
2nd STAGE
1st STAGE
FLASH VAPOR
ECONOMIZER
COOLER

Figure 63. Method of Refrigerant Control

ORIFICE METERING SYSTEM. Centrifugal water chiller system metering devices have traditionally been designed to incorporate float assemblies. However, one manufacturer uses a method that eliminates these float assemblies and has no moving parts; therefore requiring no maintenance. Elimination of the floats is a significant achievement. A multiple orifice system without moving parts operates to meter the proper amount of liquid at all levels of load without allowing a large amount of refrigerant to bypass. Referring to figure 64. There are the equivalent of six expansion and contraction areas. These are designed to maintain a refrigerant-liquid seal and prevent gas bypass. As the load requirement drops, there is a corresponding drop in the amount of liquid refrigerant delivered by the condenser. The reduced hydrostatic head causes more gas to flash in the downstream orifices. This, in turn, reduces the amount of liquid that can be handled by the upstream orifices and maintains a liquid-refrigerant seal over a wide range of operation.

At the point of minimum operating load, only a small amount of liquid supply is required to the cooler, the multiple orifice flow restricts the amount of gas bypass to an insignificant amount.

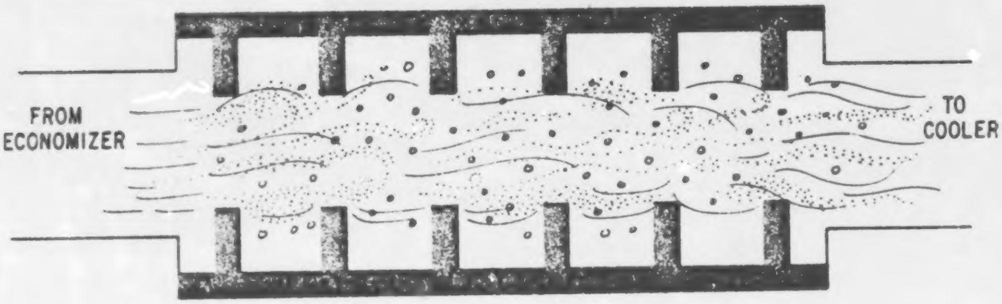

Figure 64. Orifice Metering Device

The refrigerant flow through a centrifugal machine using the orifice metering device is shown in figure 65, and is as follows. Heat from the water to be chilled is transferred to the liquid refrigerant in the cooler. This causes the refrigerant to boil and turn to a vapor. The vaporized refrigerant is directed through an eliminator, which removes any entrained liquid, and then is drawn into the compressor first stage (2). Here it passes through the first stage and second stage of compression, where centrifugal action compresses it to condenser pressure (3). The condenser water within the tubes removes the heat from the vapor, changing it to a liquid. Flash gas is accumulated by the economizer (4) and directed back to the second stage of the compressor, avoiding the first stage which reduces power consumption. The liquid flows to the evaporator, passing through the multiple orifice flow control (5). When it returns to the evaporator (1), the cycle has been completed.

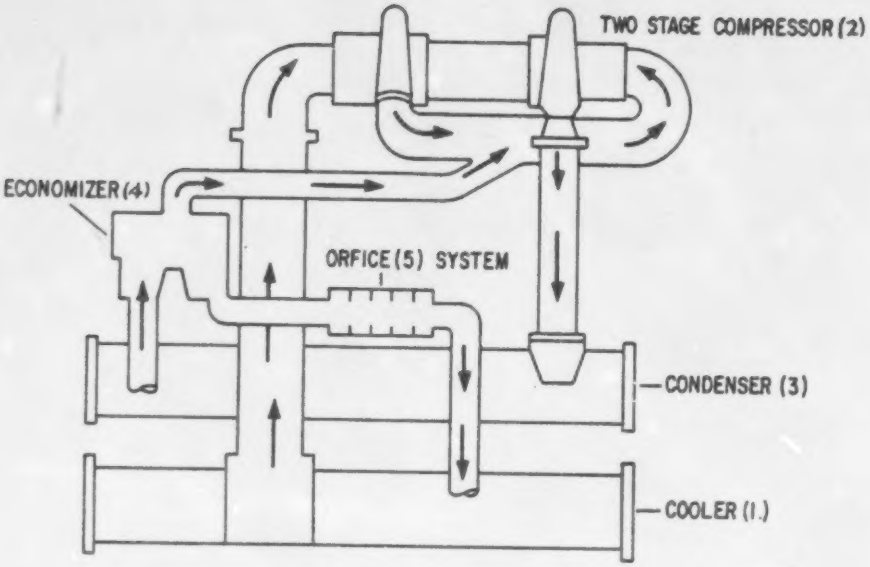

Figure 65. Refrigerant Flow in an Orifice Metering System

Compressor

Centrifugal refrigeration equipment is usually categorized by the type compressor--open or hermetic. An open compressor means the impeller shaft projects outside the compressor housing for use with an external drive. Many methods have been devised to provide the driving force for open machines. The type used with open compressors usually requires speed increases such as a gearbox. One exception is the steam turbine type which is directly connected to the compressor. This steam turbine is selected to drive at the design speed of the centrifugal impeller, therefore no speed increaser or gearing is required. A major advantage of the steam turbine is the exhaust from the turbine may have many other uses. There are some installations where this exhaust is used to operate an absorption refrigeration machine.

Gasoline and diesel engines are also used for driving open-type centrifugal machines. In the past these drives were limited to industrial applications and uses at remote military sites. Today, however, their use is becoming more widespread.

Open-type centrifugal machines are also driven by electric motors. The most common of these are the squirrel-cage induction, wound rotor, and synchronous. These motors usually operate between 1750 and 1800 rpm. A gearbox for increasing the compressor speed to 7000 to 8000 rpm is required to operate the compressor at its design speed.

PREFERRED TYPE. The modern trend of design for centrifugal machines is the hermetic type. In a hermetic compressor, an electric motor is built into the unit. It is completely isolated from the atmosphere and the motor is cooled by the refrigerant. Hermetic compressors use only induction-type motors since brush and commutators cannot be used in a refrigerant atmosphere, any arcing would cause the refrigerant to break down. Hermetic compressors are available with rpm ranges of approximately 3550 to 18000. At the present time, high rpm machines are confined to the smaller capacity machines. These factory assembled units are designed for high efficiency and easy serviceability. The single package design contains all refrigeration, drive, lubrication, purge and control components making them very compact and easy to install.

OPERATION. Stated simply, the compressor is a machine that removes evaporated refrigerant vapors, compresses these vapors, and discharges them into the condenser.

For our discussion we will use the 100-ton centrifugal system located here at the school. The operation of this machine is typical of "open" compressors found on centrifugal machines.

The easiest way to understand the functions of a centrifugal compressor is to think of it as a centrifugal fan of the type used for forced and induced draft. Like the fan, the compressor takes in gas and whirls it at a high speed, which compresses the gas by centrifugal force. The high velocity of the gas leaving the impellers is converted to a pressure exceeding the inlet pressure. At maximum speed, the compressor will produce a suction temperature of approximately 60°F below the condensing temperature of R-11. Changing speed varies suction temperature.

The compressor casing and the various stationary passages inside the compressor are made of cast iron. The compressor shaft is made of hard steel, turned and ground with keyways for each impeller, while the impellers are of the built-up type. The hub disc and cover are machined steel forgings. The blades are sheet steel, formed to curve backward with respect to the direction of rotation and riveted to the hubs and covers. After assembly, the wheels are given a hot-dipped lead coating to reduce corrosion damage. The compressor rotor assembly consists of the shaft and impellers. The shaft runs in two sleeve-type bearings.

Thermometers are inserted in the top of each bearing cover for obtaining bearing temperature. Each bearing also has two large oil rings to assure lubrication when the machine is starting up or slowing down.

Brass labyrinth packing in the diaphragms prevents interstage leakage of gas. Similar packing on the shaft at the ends of the casing restricts the flow of gas between the main compressor casing and the bearing chambers.

In operation, the pressure differential across each impeller produces an axial thrust toward the suction end of the compressor. This thrust is supported by a "Kinsbury" thrust bearing at the suction end of the shaft.

Motor

The motor drive unit is a polyphase, induction motor, 440-volts, 1755-rpm, 120-amps, manufactured by Ideal Electric Manufacturing Company. The purpose of the motor is to drive the compressor at proper speed as load requirements demand.

Speed Increaser

The speed increaser is a separate component mounted between the compressor and motor. (The gears are speed increasers required to obtain the proper compressor speed through the use of standard speed motors.) In general, the gears are of the double-helical type, properly balanced for smooth operation, and pressure lubricated. The gear wheel and pinion are enclosed in an oil-tight case which is split at the horizontal centerline. Lubrication is from a gear-type oil pump. The unit has an oil level sight glass, pressure gage, an externally mounted oil strainer and oil cooler.

LUBRICATION. The oil pump is a gear type. When assembling, care must be taken to see that the paper gasket between the pump body and brackets is of the proper thickness. A gasket which is too thick will reduce pump capacity and cause an oil pressure failure. An excessively thin gasket will cause unnecessary load on the gears, resulting in wear and destruction of the gears. Writing paper makes a good gasket when shellacked in place. Never use rubber for any gasket used for oil.

A good gear oil must be used for the lubrication of high-speed gears. The oil must be kept clean by filtering, and filters must be changed as often as possible. The temperature of the oil should be kept approximately 130°F--180°F. Water cooling should be used whenever necessary to keep the temperature within these limits.

Selection of the best grade of oil for use on a gear is based on journal speeds, tooth speeds, and clearances. In general, it is better to use an oil that is too heavy than one too light. The gears will be somewhat warmer, but the heavier oil will take care of the higher temperature if it is not more than a few degrees. The heavier oil is rated at 400 to 580 seconds viscosity.

WATER COOLING OF GEARS. Cooling of the gears is accomplished by circulating water through water jackets cast in the ends of the gear casing or by means of either an internal or external oil cooler. This system is connected to a supply of cool, clean water at a minimum pressure of 4 pounds. A regulating device must be installed in the water supply line. The discharge line should have free outlet without valves to avoid possibility of excessive pressures on the system. Piping must be arranged so that all the water can be drained or blown out of the water jackets or cooler if the unit may be subjected to freezing temperatures.

MAINTENANCE. Inspect to see that both the driving and driven machines are in line. If you are not sure that alignment is correct, check and align if necessary. Try out the water cooling system to see if it is functioning properly. When starting, see that you have sufficient oil in the gear casing and that the oil pump gives required pressure (4 to 8 lbs). When the temperature of the oil in the casing reaches 100°F, turn on the water cooling system. Add sufficient oil from time to time to maintain the proper oil level. Never allow the gearwheel to dip into the oil.

Regular cleaning of the lubrication system and testing the lubricant for impurities are essential. Clean the strainer at least once a week. The manufacturer recommends the gearcase be drained and completely cleaned every two--three months. Refill with new filtered oil. From time to time, samples of oil should be drawn and the oil checked for impurities. If water is present, the water should be drawn off; and, if there is a considerable amount of water in the oil, remove all oil and separate water from the oil before it is used again.

All working parts are easily accessible for inspection and repair except the oil pump. If the occasion arises to dismantle the gears, extreme precautions must be taken to prevent any damage to gear teeth. The slightest bruise will result in a noisy operation. When the gears are removed, place them on a clean cloth-covered board and block them so that they cannot roll off. Cover gears with cloth for protection purposes.

Bearing shells and oil slingers are marked and should be reinstalled in their proper places. Gaskets are used between the oil pump bracket and oil pump, and under handhole covers. All parts must be clean when reassembling. Make sure that no metal burrs or cloth lint are present on any part of the unit. Coat faces of flanges with shellac before they are bolted in place. A thin coat of shellac on the bearing supports will prevent oil leaks at these places.

When bearings are worn, they must be replaced immediately. Worn bearings will cause gears to wear. Bearings are interchangeable and when new bearings are installed, the gears are restored to their original center distance and alignment. It is not recommended to rebabbitt bearings; the heat required to rebabbitt bearings will cause some distortion of the bearing shell. Do not install one new bearing alone; always install in pairs. This will help eliminate tooth misalignment.

"Cinch" fittings are used on all pipes connected to the oil pump bracket; use this type on all replacements. Threaded fittings may cause the bracket to be pulled out of line, causing noisy operation and wear on gears.

Couplings should not be driven on or off the gear or pinion shafts, as hammering may injure both surfaces. Provisions have been made for using a jacking device for installing or removing couplings from shafts.

Gear tooth contact and wear should be uniformly distributed over the entire length of both gear and pinion helixes. If heavier wear is noted on any portion of the helixes or any part of the tooth face, it may indicate improper setting of the gear casing, misalignment of connecting shafts, vibration, excessive or irregular wear on the bearings, or poor lubrication. Should gear teeth become damaged during inspection or operation, remove burrs by use of a fine file or oilstone. Never use these tools to correct the tooth contour.

Misalignment, poor lubrication, and vibration can cause pitting of tooth surfaces or flaking of metal in certain areas of the gears. If this happens, check alignment and remove all steel particles.

Couplings

The couplings used to connect the motor to the speed increasing gears and from the gears to the compressor are self-aligning couplings. The coupling is of the flexible geared type, consisting of two externally geared hubs that are pressed on and geared to the shafts. These hubs are enclosed by a two-piece, externally geared, floating cover which functions as a single unit when the halves are bolted together. The cover is supported on the hub teeth during operation. A spacer or spool piece is used with the cover for the compressor coupling. The hub teeth and cover teeth are engaged around the complete circumference and the cover and shafts revolve as one unit. The cover and each shaft are free to move independently of each other within the limits of the coupling, thus providing for reasonable angular and offset misalignment as well as end float.

The amount of misalignment that the coupling will handle without excessive stressing varies with the size of the coupling. In all cases, however, it should be treated as a coupling taking care of incidental misalignment and should never be considered as a universal joint.

Flexible couples are generally the type used on most centrifugal units. They will insure long life if properly maintained. The two most important operating services to insure long life are proper lubrication and proper alignment.

COMPRESSOR LUBRICATING SYSTEM

Characteristics

The compressor has a forced lubrication system, figure 66, including oil pump, bearing oil rings, pressure regulating valves, etc. The entire oiling system is housed within the compressor casing and the oil is circulated through cored openings, drilled passages, or fixed copper lines. This eliminates all of the usual external lines and their danger of possible rupture, damage, or leakage. All of the oil for the lubricating system is circulated by a helical gear pump, which is submerged in the main oil reservoir. The simple, positive drive assures ample oil for pressure lubricating and cooling all journal bearings, thrust bearings, and seal surfaces.

The reservoir which houses the oil pump is an integral part of the compressor casing and is accessible through a cover plate on the end of the compressor. Circulating water cooling coils are fitted to the cover plate to maintain proper oil temperature.

A high grade turbine oil, such as DTE heavy medium or approved equivalent, is recommended for centrifugal compressors. To be sure of the specifications on grade and type of oil to use, it is advisable to refer to the manufacturer's maintenance manual. The oil in the centrifugal compressor should be changed annually.

Procedures

INITIAL PROCEDURES. If a machine is to be started for the first time, or if all the oil has been drained from the unit, the following lubrication procedures are recommended:

1. The machine pressure must be atmospheric.

2. The cover on the front bearing (coupling end of the compressor) is removed and one gallon of oil is poured into the front bearing.

3. Fill the seal oil pressure chamber by removing the cover.

4. Remove the cover from the rear bearing and pour oil into the chamber until the indicated height is reached as recommended on the plate on the pump chamber.

5. Fill the atmospheric float chamber through the connection on the side of the chamber until oil shows in the sight glass, see figure 66.

6. Pour a small amount of oil into the thrust bearing housing by removing the strainer cap and pouring into the strainer.

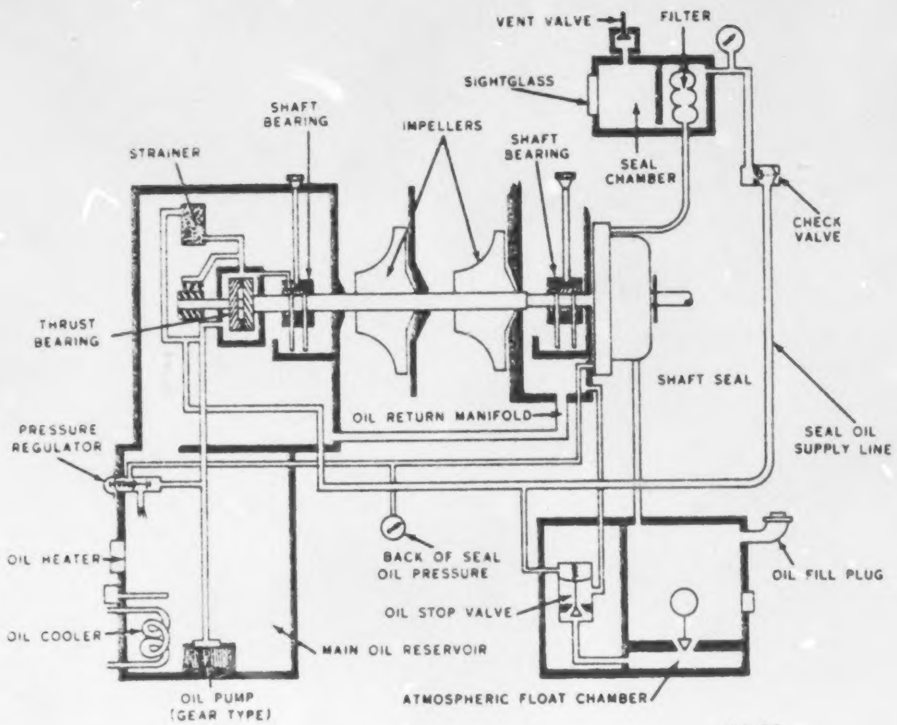
VENT VALVE
FILTER
SIGHTGLASS
SHAFT BEARING
IMPELLERS
SHAFT BEARING
SEAL CHAMBER
STRAINER
CHECK VALVE
THRUST BEARING
SHAFT SEAL
OIL RETURN MANIFOLD
PRESSURE REGULATOR
SEAL OIL SUPPLY LINE
OIL HEATER
BACK OF SEAL OIL PRESSURE
OIL FILL PLUG
OIL STOP VALVE
OIL COOLER
MAIN OIL RESERVOIR
OIL PUMP (GEAR TYPE)
ATMOSPHERIC FLOAT CHAMBER
CMD-032

Figure 66. Oil Piping Diagram

NORMAL PROCEDURES. Under normal operating conditions, the following lubrication procedures are recommended:

1. Replace the oil filter regularly, depending on the length of operation.
2. If, at any time, oil is withdrawn from the machine, replace it with new oil.
3. Clean and inspect the strainer in the thrust bearing at least once a year.
4. Replace the complete oil charge at least once a year.
5. After shutdown periods of more than a month, remove the bearing covers and add one quart of oil to each bearing well before starting.

OIL DRAINAGE. To drain the oil system, allow the machine to warm up until the temperature is approximately 75°F. The machine must be at atmospheric pressure. The pump chamber is drained by removing the drain plug. Replace the plug, then drain the atmospheric float chamber in the same manner. By draining these two chambers, practically all of the oil is removed. The oil left in the bearing wells and seal reservoir maintains the bearings in satisfactory condition and for sealing purposes.

To keep the machine in the best operating condition, the following precautions must be observed:

1. The electric heater in the oil pump chamber must be turned on during shutdown periods, and must be turned off when the cooling water is turned on. The purpose of this heater is to keep the R-11 and oil separated.

2. Do not overcharge the system with oil. The oil level will fall as the oil is circulated through the system; but under normal operation, the oil level will increase approximately 7 percent in volume as the oil absorbs refrigerant. The oil level in the machine will be approximately one-half sight glass.

3. Oil can be added to the machine at the filling connection, figure 66, on the side of the atmospheric float chamber only while the machine is in operation and the atmospheric float chamber return valve is open.

Compressor Shaft Seal

A shaft seal is provided where the shaft extends through the compressor casing. The seal is formed between a ring called the rotating sealing seat, fitted against a shoulder on the shaft, and the stationary sealing seat attached to the seal housing through a flexible member or bellows assembly. The contact faces on these seal seats are carefully machines and ground to make a vacuum tight joint. A spring, called the multileaf seal spring, moves the stationary seal seat to contact the rotating seal seat. This makes the proper seal when the compressor is shut down. A floating ring is located between the hub of the stationary sealing seat and the hub of the rotating sealing seat. A seal oil reservoir and filter chamber are attached to the compressor housing above the seal which maintains a head of oil to the seal surface during shutdown periods.

HERMETIC COMPRESSORS

As was mentioned earlier, the modern trend of design for centrifugal machines is the hermetic type. This single package design contains all components for the refrigeration, drive assembly, lubrication, purge, and controls.

Cooling

In a hermetic compressor, an electric motor is built into the unit. It is completely isolated from the atmosphere and the motor is cooled by the refrigerant. Several methods have been devised by various manufacturers to accomplish this. A few are as follows:

Refer to figure 67. The integral compressor motor is cooled directly by the system refrigerant. Liquid refrigerant for motor cooling is taken directly from the condenser liquid sump, through a filter drier, to connections in the end shields of the motor. Liquid refrigerant passes through the end shield connections to large diameter, low-velocity spray nozzles in the motor labyrinth seals and is sprayed directly into the motor cavity. Because the liquid refrigerant is taken below the liquid return to the cooler, there is a constant supply of liquid refrigerant to the motor at all times, even at start up.

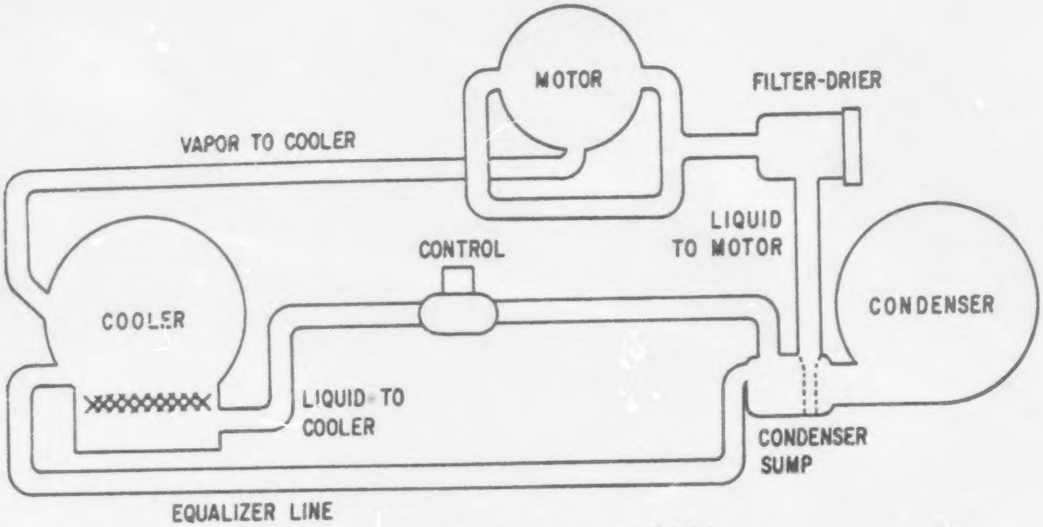
MOTOR
FILTER-DRIER
VAPOR TO COOLER
LIQUID
TO MOTOR
CONTROL
COOLER
CONDENSER
LIQUID TO
COOLER
CONDENSER
SUMP
EQUALIZER LINE

Figure 67. Spray Cooling of Motor

The liquid refrigerant absorbs the motor heat, changes to a vapor, then flows to the bottom of the motor frame and enters the cooler below the eliminators.

Another method of motor cooling is shown in figure 68. In this system, the flash gas from the economizer is drawn through the eliminator, which removes any droplets of liquid refrigerant. The gas is directed around the stator and through the air gap to provide adequate motor cooling. It is then drawn into the suction side of the second-stage impeller where it mixes with the discharge gas of the first-stage impeller and reenters the basic cycle.

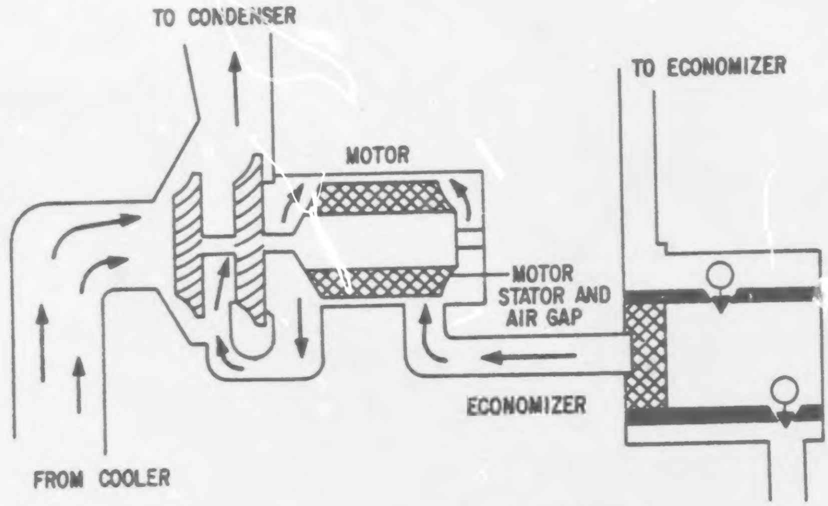
TO CONDENSER
TO ECONOMIZER
MOTOR
MOTOR
STATOR AND
AIR GAP
ECONOMIZER
FROM COOLER

Figure 68. Gas Cooling of Motor

Still another method of motor cooling is shown in figure 69. This system utilizes no moving parts or high pressure sprays. In this gravity-operated sytem, the liquid refrigerant never touches any moving parts of the motor. A proper supply of refrigerant is delivered to the motor from a special economizer sump before any refrigerant is transferred to the cooler. In this system, gravity causes the liquid refrigerant to seek the same level maintained in the economizer sump, thereby, effecting motor cooling. The motor stator is immersed in an isothermal bath of liquid refrigerant, the temperature of which corresponds to the economizer pressure. This system maintains a constant and uniform temperature throughout the motor assembly.

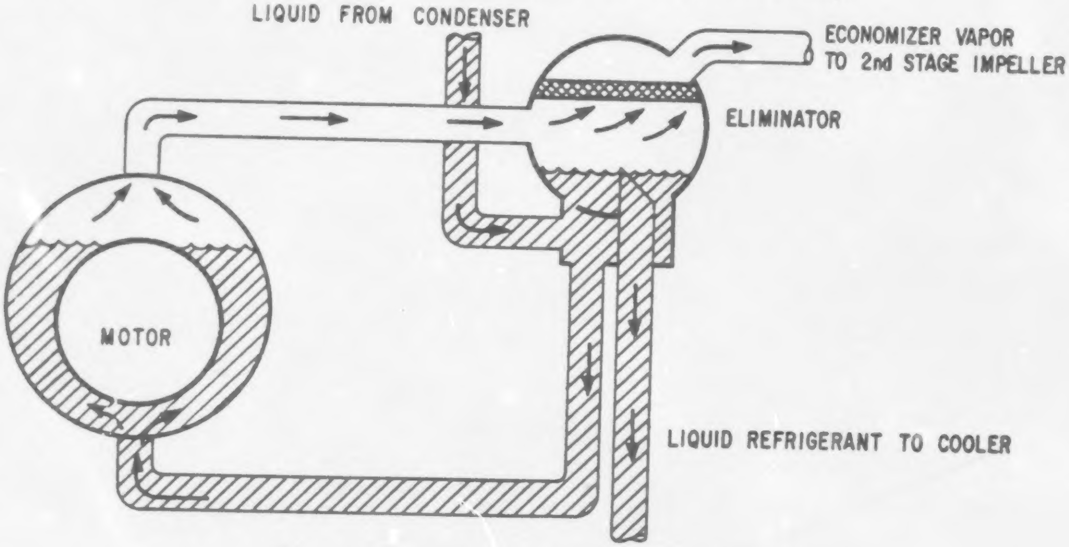
LIQUID FROM CONDENSER
ECONOMIZER VAPOR TO 2nd STAGE IMPELLER
ELIMINATOR
MOTOR
LIQUID REFRIGERANT TO COOLER

Figure 69. Isothermal Bath Motor Cooling

Hermetic Lubrication System

A typical example of the hermetic compressor bearing lubrication circuit is shown in figure 70. Positive lubrication of the motor bearings is provided by the use of a pressurized lubrication system.

The oil tank is located immediately below the compressor motor and receives the oil returned from the motor bearings. Within this tank a hermetic electric pump maintains a constant supply of oil at a constant pressure differential between the oil tank and motor bearings by means of an oil pressure relief valve. A strainer-drier in the oil line to the bearings assures a constant supply of clean, dry, (moisturefree) oil.

Any refrigerant vapor in the lubrication system is eliminated through a surge tank and vent line, vented to the input of the compressor first stage, thus maintaining the oil tank at the lowest possible refrigerant pressure. Two electric heaters, thermostatically controlled, maintain the oil at a temperature sufficiently higher than the saturated refrigerant temperature at idle and operating conditions to prevent dilution of the oil and to minimize foaming at startup. Because of the efficient motor cooling systems used, the oil returning from the bearings is never warmer than the supply to the bearings. Therefore, no oil cooler is used. A pressure gage on the control panel indicates oil pressure to the bearings. A thermometer on the oil tank indicates the temperature of the supply oil. The oil tank contains a sight glass which permits observation of the oil supply. The parts of the lubrication system are accessible for servicing by removing the oil tank cover plate.

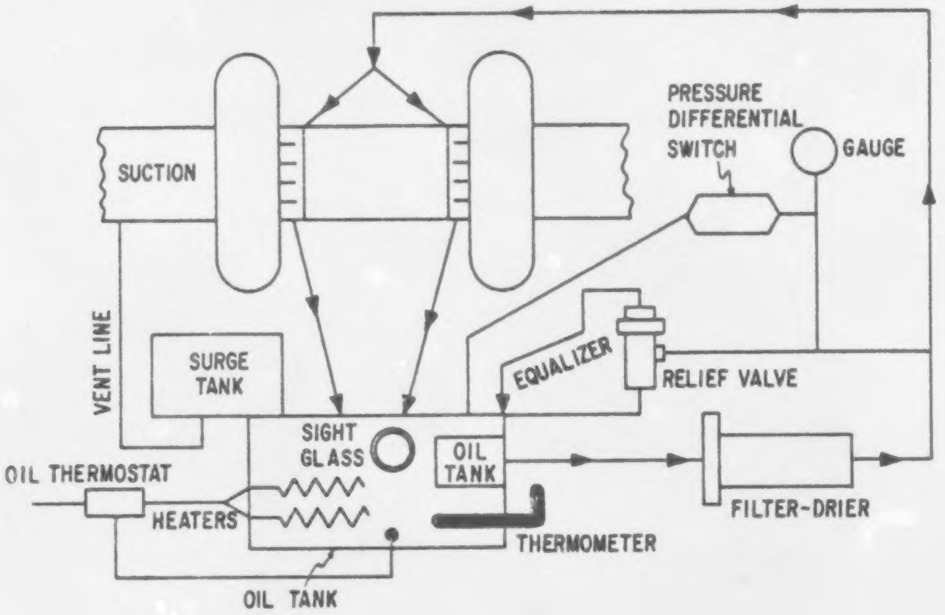
PRESSURE DIFFERENTIAL SWITCH
GAUGE
SUCTION
VENT LINE
SURGE TANK
EQUALIZER
RELIEF VALVE
SIGHT GLASS
OIL TANK
OIL THERMOSTAT
HEATERS
FILTER-DRIER
THERMOMETER
OIL TANK

Figure 70. Bearing Lubrication Circuit

Unishell Construction

On some centrifugals, coolers and condensers are constructed into a single shell as shown in figure 71. The upper section is the condenser and the lower section is the cooler. A division plate separates the two chambers. Liquid refrigerant drops to the bottom of the condenser where it flows by gravity into the float chamber to the cooler.

The cycle of operation for unishell machines is the same as was discussed previously with a few minor exceptions in the capacity control systems, which will now be discussed.

Capacity Controls

Listed below are the three methods of controlling the capacity output of a centrifugal machine.

1. Controlling the speed of the compressor.
2. Throttling the suction of the compressor.
3. Increasing the discharge pressure of the compressor.

The three methods given are listed in order of their efficiency. At partial loads, the power requirements will be the least if the compressor speed is reduced--not quite as low if the suction is throttled--and highest if the condenser water flow is throttled to increase the discharge pressure.

COMPRESSOR SPEED CONTROL. When a compressor is driven by a variable speed wound rotor motor, compressor speed is controlled by varying the resistance in the rotor circuit by means of a "Drum Controller."

SUCTION DAMPER CONTROL. Throttling the suction of the compressor is obtained by a throttling damper built into the evaporator suction flange. The suction damper is controlled by a temperature controller that sends an air signal to the suction damper motor in response to temperature changes of the chilled water leaving the cooler.

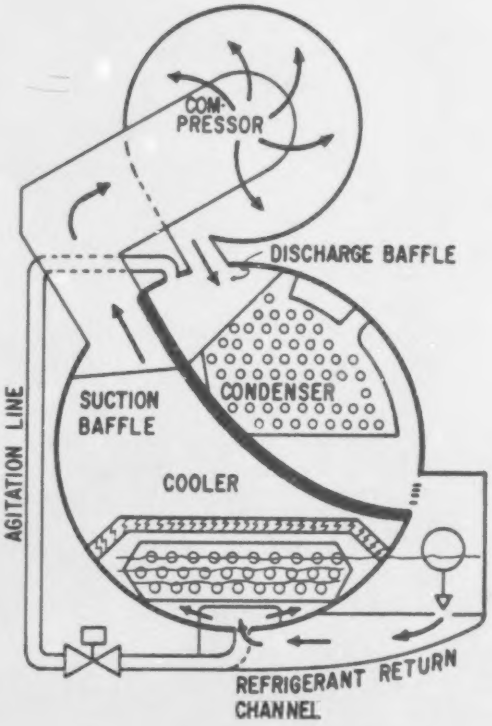

Figure 71. Single-Shell Construction

CONDENSER WATER TEMPERATURE CONTROL. By throttling the condenser water flow, the condenser pressure can be increased, thereby increasing the pressure differential on the compressor and reducing its capacity. Occasionally, the lowest speed may be insufficiently low to meet the operating conditions. In such a case, the condenser water flow may be throttled to bring the compressor operating conditions within range of the speed control.

A thorough discussion of the adjustment of the capacity control systems will be discussed under operational controls. First, let's look at a study of the unishell machines.

Agitation Line

At extremely light loads on unishell machines, there may be an excess of refrigerant in the cooler, and because low heat is being supplied by the chilled water, there is little vaporizing or boiling of the refrigerant. This causes the upper tubes to be exposed to a gas. The relatively warm water would cause more superheat to be added to the gas, impairing the efficiency of the machine. To improve this extremely low-load condition operation, a line is connected between the top of the condenser and the bottom of the cooler. At a predetermined light load setting a switch energizes a solenoid valve and allows high pressure condenser gas to flow into the refrigerant distribution channel causing agitation of the liquid so that the upper tubes are subjected to liquid refrigerant, consequently more efficient cooling of the chilled water takes place. Refer to figure 71.

Purge Units

The presence of even a small amount of water in a refrigeration system must be avoided at all times, otherwise excessive corrosion of the system may occur. Any appreciable amount of water is due to a leak from one of the water circuits.

The pressure within a portion of the centrifugal refrigeration system is less than atmospheric; therefore, the possibility exists that air may enter the system. Since air contains water vapor, a small amount of water will enter whenever air enters.

The function of the purge system is to remove water vapor and air from the refrigeration system and to recover the refrigerant which is mixed with these gases. The secondary function of the purge unit (covered later under System Maintenance) is to pressurize the centrifugal machine for refrigerant removal.

The air is automatically purged to the atmosphere. The refrigerant is condensed and automatically returned to the cooler as a liquid. Water, if present, is trapped in a compartment of the purge separator unit from which it can be drained manually. Thus, the purge recovery system maintains the highest possible refrigerating efficiency.

PURGE RECOVERY OPERATION. The purge recovery operation is automatic, once the purge switch is turned ON and the four valves listed below referred to in figure 72 are opened.

1. Service valve on main condenser.
2. Hand valve in suction line.
3. Hand valve in the return liquid refrigerant line.
4. Service valve on economizer in return liquid refrigerant line.

NOTE: Water drain hand valve must be closed during normal operation.

If there should be an air leak in the system, operation of the purge unit will remove the air. It is recommended that the operator stop the purge unit at intervals and shut off valves (2) and (3) listed above, to check for leaks in the purge system. A tight machine will not collect air no matter how long the purge unit is shut off.

Presence of air in the centrifugal unit is shown by an increase in head pressure in the condenser. The pressure can develop suddenly or gradually during machine operation. Checking the difference between leaving condenser water temperature and the temperature on the condenser gage may be used to determine the presence of air. A sudden increase between these temperatures may be caused by air. In some instances, a sudden increase in cooler pressure over the pressure corresponding to cooler temperature during operation, may be caused by air leakage.

Small air leaks are very difficult to determine. It may take one or more days to detect an air leak in the machine. A leak that shows up immediately or within a few hours is large and must be found and repaired immediately.

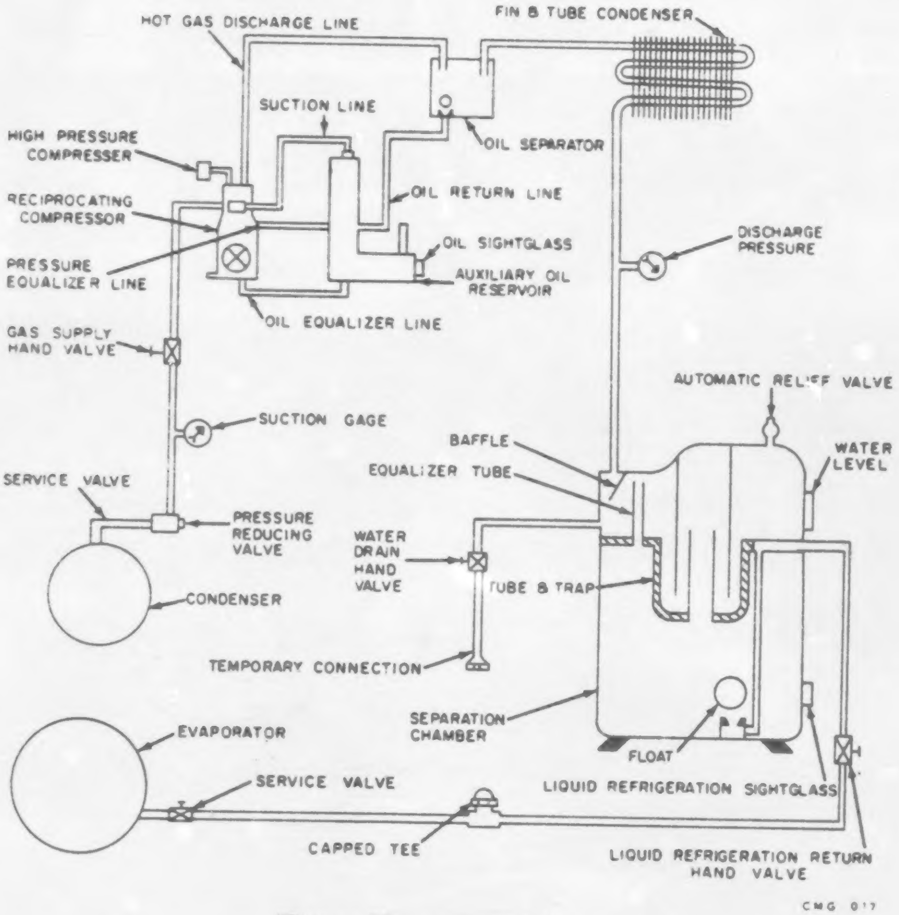
HOT GAS DISCHARGE LINE
FIN & TUBE CONDENSER
SUCTION LINE
HIGH PRESSURE COMPRESSER
OIL SEPARATOR
RECIPROCATING COMPRESSOR
OIL RETURN LINE
OIL SIGHTGLASS
DISCHARGE PRESSURE
PRESSURE EQUALIZER LINE
AUXILIARY OIL RESERVOIR
OIL EQUALIZER LINE
GAS SUPPLY HAND VALVE
AUTOMATIC RELIEF VALVE
SUCTION GAGE
BAFFLE
WATER LEVEL
EQUALIZER TUBE
SERVICE VALVE
PRESSURE REDUCING VALVE
WATER DRAIN HAND VALVE
TUBE & TRAP
CONDENSER
TEMPORARY CONNECTION
SEPARATION CHAMBER
EVAPORATOR
FLOAT
SERVICE VALVE
LIQUID REFRIGERATION SIGHTGLASS
CAPPED TEE
LIQUID REFRIGERATION RETURN HAND VALVE
CMG 017

Figure 72. Purge Unit

Refrigerant loss depends on operational conditions; therefore, these conditions have a determining effect on refrigerant losses. The operator should be very careful in maintaining his log on refrigerant charged and the shutdown level in the cooler. In this manner, he can determine when the leak developed, the refrigerant loss, and find the cause, to correct the trouble.

If there is a slight leak in the condenser during operation, and the purge indicates a large air gain in the system during shutdown and the machine is under a vacuum, then a serious leak exists on the high-pressure side. The leak must be found and corrected.

Moisture removal by the purge recovery unit is just as important as air removal. Moisture may condense in the machine from air leaking into the machine or by a water leak in the cooler or condenser. If there are no water leaks, the amount of water collected by the purge unit will be small (one ounce per day) under normal operating conditions. If large amounts of water are collected by the purge unit (one-half pint per day), the machine must be checked for leaky tubes. Water must be removed manually by opening the water drain hand valve. If water does collect, it will appear in the sight glass and should be drained. Water can be removed more rapidly when the machine is stopped than when running. If the machine is collecting large amounts of moisture, it is advisable to run the purge unit a short time after the machine is stopped and before it is started. Running the purge unit before the machine is started will help to reduce purging time, after the machine is started.

The automatic relief pressure valve is related to room temperature as shown in Table 1, and can be adjusted by a screwdriver after removing the top cover of the purge unit casing. For recommended pressures within the condenser pressure limits, refer to Table 1.

Room Air Temperature	65	75	85	95	105	115
Suction-Pressure (Maximum Allowable)	5 Inch Vacuum	0-lb 0-lb Gage	3.5 lb Gage	7 lb Gage	Wide Open	Wide Open
Relief Pressure by Adjustment of Automatic Relief Valve	75-80	75-80	95-100	95-100	105 - 110	105-110

Table 1

The pressure reducing valve is adjusted to produce a suction pressure on the purge unit and will not allow condensation in the suction line. If condensation does occur, the condensate will collect in the crankcase of the purge compressor, causing a foaming and excessive oil loss. Table 1 can be used as a guide for setting the pressure reducing valve.

LUBRICATION. The purge unit compressor and centrifugal compressor use the same type and grade of oil. Oil can be added to purge compressor by closing the hand valves, (2) and (3) listed under Purge Recovery Operation, removing the plug in the top of the oil sight glass, and adding oil. Draining the oil is accomplished by removing the oil plug below the purge compressor. The oil level is checked by a showing of oil at any point in the sight glass. This can be accomplished while the compressor is running or shut down. The level of oil will fluctuate accordingly. The oil level should be checked daily.

MAINTENANCE. Other components that must be closely checked in the purge recovery unit are as follows.

1. Belt tension.
2. Relief valve for tighteness when closed to prevent loss of refrigerant.
3. Condenser clean and free of air obstruction.
4. High-pressure cutout shuts down the unit if the condenser pressure reaches 110 pounds.

CAUTION: The high-pressure cutout remakes contact automatically to start the purge unit on 75 lbs. Single-phase motors have a built-in thermal overload stopping the motor on overload. It automatically resets to start the motor in a few minutes.

A liquid rise in the upper sight glass of the purge chamber indicates a malfunction and is usually caused by a **valve** being closed or because the float valve is not operating. Immediate action must be taken to correct this trouble. If the liquid is not visible in the lower sight glass, the float valve is failing to close properly.

OPERATIONAL CONTROLS

The operational controls are as follows:

1. Compressor speed control.
2. Suction damper control.
3. Condenser water temperature.
4. Hot gas bypass.

Drum Controller

The drum controller is used to adjust the amount of resistance in the rotor circuit of the motor. Resistors are used with the drum to provide speed regulation and act as an energy dissipating unit. The maximum amount of energy turned into heat in the resistors amounts to about 15 percent of the motor rating. The grid resistors perform two functions. First, to limit the starting current when the motor is accelerating from standstill to operating speed; and, second, to regulate the operating speed of the motor. The drum adjusts the amount of resistance in the rotor circuit. Resistors are provided with connection lugs corresponding to the connection lugs on the drum. The resistors limit the motor starting inrush current to 150 percent of full load motor starting current and provide 25 percent speed reduction below full load speed of the motor. The drum resistors are connected to the sliprings. The Cutler-Hammer drum controller provides balanced resistor speed control points which are clearly indicated on the drum head. Drum points that are not numbered, are unbalanced resistor points for acceleration only. The motor should not be permitted to dwell on any of the unbalanced speed points. These points serve only to limit the acceleration current drawn by the motor. An electrical interlock circuit in the drum consists of three contact fingers and cylinder contacts below the main contacts. It also provides the electrical connection in the full resistance position to allow the primary switch or circuit breaker to apply power to the motor. The interlock prevents starting the motor unless all resistance is in the motor.

OPERATION. Always bring the drum control lever to the OFF (all resistance in) position before pressing START button. Manual starting of the machine at the motor location assures the complete operator supervision of the unit. Interlocking wiring connections between drum controller and circuit breaker make it necessary to return drum control to full low-speed position (all resistance in the motor) before breaker can be closed. The oil pressure switch is bypassed when holding START button closed. Releasing START button before oil pressure switch closes will cause breaker to trip out--hence a false start.

To regulate speed, move the drum control lever to next higher balanced speed point (marked points) and pause only about one second on each unbalanced point (unmarked points). Do not allow motor to run on unbalanced speed points due to possible pulsating torque. This causes unnecessary wear on bearing, gears, and couplings.

MAINTENANCE. Isolate all power before attempting any maintenance. Drum contactors should be checked for alignment, kept lubricated with a thin coating of vasoline and kept free of excessive dirt and dust.

Suction Damper Control

Throttling the suction to the compressor is obtained by inlet guide vances located just ahead of the inlet of the first wheel of the compressor. By throttling the compressor suction, the pressure differential through which the compressor must handle the refrigerant vapor is increased. The variable vanes not only perform a throttling function, but also give a variable prerotation to the refrigerant vapor entering the compressor. Suction modulation is effected by means of a temperature controller which sends either air or electric signals to a variable inlet guide vane motor or actuator, in response to changes in the temperature of the chilled water leaving the cooler.

A typical example of the suction damper control system makes use of the Honeywell series 90 control loop. Figure 73 illustrates the variable guide vanes, the series 90 motor, and the series 90 chilled water controller.

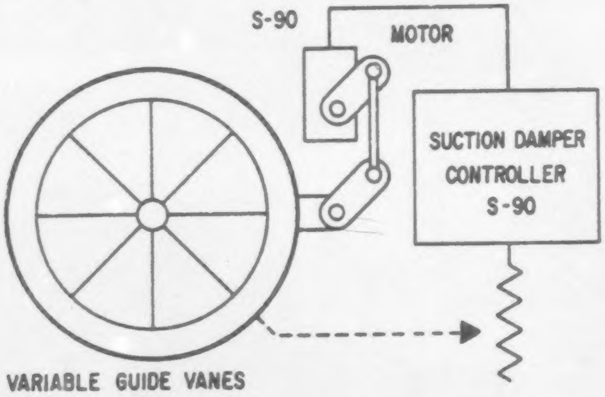

Figure 73. Suction Damper Control

SERIES-90 CONTROLLERS. Before you can fully understand the operation of a potentiometer. A potentiometer is a variable resistor. Figure 74 illustrates this component which is a number of turns of resistance wire wound on a cylinder and constructed with three connections. The center connection is a movable finger or wiper which rides over the length of the coil completing the circuit wherever it touches. The wiper can be positioned manually or automatically, by a sensing element resonding to a variable change.

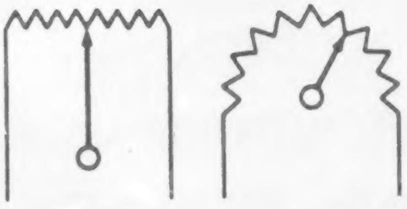

Figure 74. Potentiometers

SERIES-90 CIRCUITS. The series-90 control loop consists of two circuits. Each of them has a specific function in the overall operation of the series-90 control loop.

1. Control circuit: Figure 75 illustrates a modification of the Wheatstone bridge. It consists of two potentiometers. One potentiometer is in the controller and its wiper is moved by the sensing element, reacting to each variable change. The other potentiometer is located in the motor and its wiper is moved by the rotation of the motor. You will also note that the control circuit contains two coils and a 24-volt power source. The thermosat, in figure 75, is satisfied and the bridge is balanced. Power (24 volts) is applied to the bridge by the transformer. There are two paths for current to flow. The left circuit has a total of 135 ohms resistance plus coil C_1. The right circuit has a total of 135 ohms resistance plus coil C_2. The amount of current flow is equal in both circuits. This is called a balanced bridge.

2. Motor circuit: The series-90 motor consists of a capacitor-type reversible motor and a balancing relay. Figure 76 illustrates how a balancing relay is constructed. The motor is started, stopped, and reversed by the SPDT contacts of the balancing relay. The relay consists of two solenoid coils and a U-shaped armature. The armature is pivoted in the center and the legs extend into the hollow cores of the solenoid coil. A contact arm is fastened to the armature in such a manner that one or the other of the two stationary contacts may be engaged as the armature is moved back and forth on its pivot. When the relay is in a balanced condition, as shown in figure 76, the contact arm floats between the two stationary contacts and the motor is at rest.

SERIES-90 OPERATION. Changes in conditions at the controller repositions the potentiometer which offsets the control circuit. Now the amount of current flowing through the two relay coils is unbalanced. Whenever the current through these two coils becomes unbalanced, one of them becomes stronger and the U-shaped armature is moved.

The movement of the armature closes one of the relay contacts which in turn starts the motor running in the proper direction. If coil C_1 becomes stronger, the contact blade is moved to the left making a circuit from one side of the transformer directly to motor windings W_1. The current is also supplied to W_2 by the capacitor. The motor operates in one direction until the bridge is balanced or the limit switch opens.

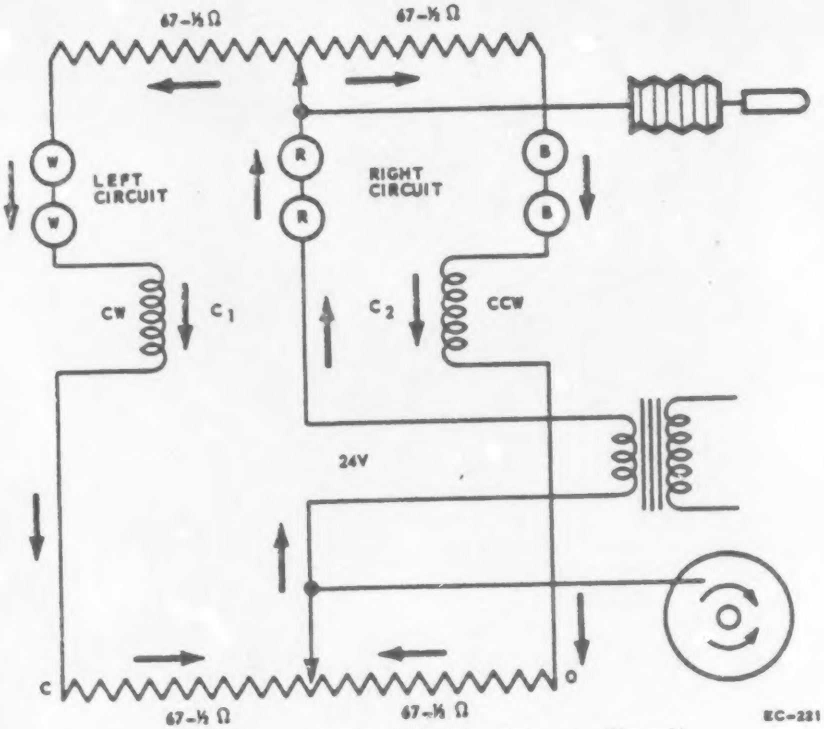
67-½ Ω
67-½ Ω
W
W
LEFT CIRCUIT
R
R
RIGHT CIRCUIT
B
B
CW
C_1
C_2
CCW
24V
C
O
67-½ Ω
67-½ Ω
EC-221

Figure 75. Series-90 Control Circuit

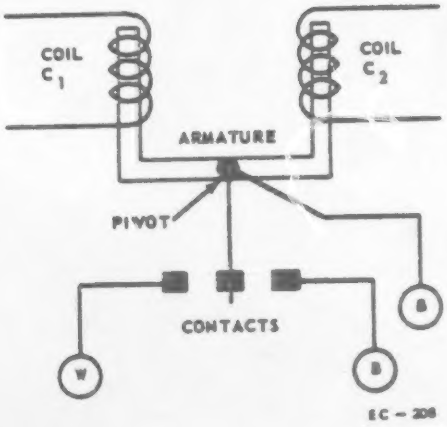
COIL C_1
COIL C_2
ARMATURE
PIVOT
CONTACTS
W
B
B
EC - 208

Figure 76. Diagram of a Balancing Relay

If coil C_2 becomes the stronger, the right-hand contact is made and W windings are directly powered while winding W_1 is powered by the capacitor. The motor is again energized but now in the opposite direction.

Figures 77, 78, and 79 are diagrams of the series-90 control circuit at work in various modes of operation.

Figure 77 shows an instantaneous condition in which the current is flowing from the transformer, through the potentiometer pointer, and down through both legs of the circuit. In the positions shown, the thermostat potentiometer pointer and the the motor balancing potentiometer pointer divide their respective coils so that R1 = R4 and R2 = R3. Therefore R1 + R3 = R2 + R4 and the resistances on both sides of the circuit are equal. The coils C1 and C2 of the balancing relay are equally energized and the armature of the balancing relay is balanced. The contact arm is floating between the two contacts, no current is going to the motor, and the motor is at rest.

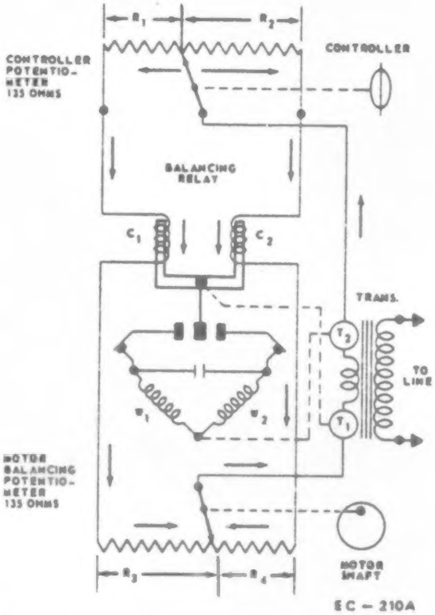
R1
R2
CONTROLLER POTENTIO-METER 135 OHMS
CONTROLLER
BALANCING RELAY
C1
C2
TRANS.
T2
T1
TO LINE
W1
W2
MOTOR BALANCING POTENTIO-METER 135 OHMS
R3
R4
MOTOR SHAFT
EC – 210A

Figure 77. Diagram of a Series-90 Control Circuit in Balanced Condition

Figure 78 shows another instantaneous condition in which the temperature had decreased a small amount. As a result, the pointer of the thermostat potentiometer has moved toward the right end of the potentiometer coil. The amount of resistance on both sides of the circuit is no longer equal (R1 + R3 is greater than R2 + R4). The greater share of the current now flows through the right leg of the circuit and coil C2 of the balancing relay exerts a greater force on the armature than does C1. The armature has rotated, making contact to the side of the circuit that sends current directly to motor winding W2. The motor is running in the corresponding direction and moving the motor balancing potentiometer to a new position.

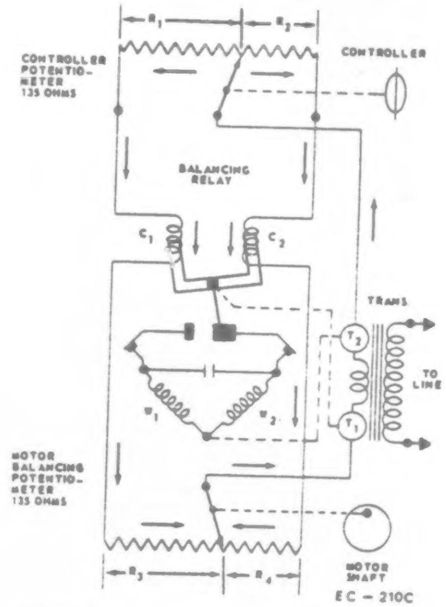
R1
R2
CONTROLLER POTENTIO-METER 135 OHMS
CONTROLLER
BALANCING RELAY
C1
C2
TRANS.
T2
T1
TO LINE
W1
W2
MOTOR BALANCING POTENTIO-METER 135 OHMS
R3
R4
MOTOR SHAFT
EC – 210C

Figure 78. Diagram of Series-90 Control Circuit on Drop in Temperature. The circuit is unbalanced.

Figure 79 shows an instantaneous condition after the motor shaft has moved the motor balancing potentiometer to a position which equalizes the current passing through the two legs of the circuit. In this condition, the right side of the thermostat potentiometer has a resistance equal to that of the left side of the motor balancing potentiometer. Likewise, the resistance of the left side of the thermostat potentiometer is equal to that of the right side of the motor balancing potentiometer. Again, R1 + R3 = R2 + R4, current flowing through the two legs of the circuit is equal, and the motor is at rest.

By careful analysis of the diagrams, it will be seen that the motor runs until the pointer of the motor balancing potentiometer reaches a position which corresponds to the position of the pointer of the thermostat potentiometer.

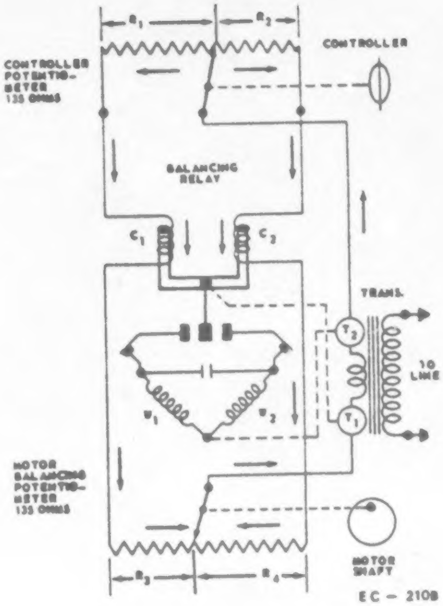

Figure 79. Diagram of Series-90 Circuit Rebalanced in New Position

Condenser Water Temperature Control

By throttling the condenser water flow, the condenser pressure can be increased, thereby increasing the pressure differential on the compressor and reducing its capacity. Occasionally, the lowest speed available on the variable speed control, may not be low enough to meet the operating conditions. In such a case, the condenser water flow may be throttled and the operating conditions may be brought up into the range of the speed control.

Hot Gas Bypass Control

The hot gas bypass is used to prevent the compressor from surging at low load conditions. Should a low load condition exist, the hot gas bypass hand valve is opened until surging stops. In reality, hot gas is bypassed directly from the condenser through a flange with a venturi (restrictor) using a small amount of liquid to desuperheat the gas. The precooled gas can then be injected into the cooler or evaporator. The hot gas supplements the small volume of gas that is evaporated in the cooler due to a low-load condition. Surging takes place when the impeller cannot get enough refrigerant vapor to keep it loaded. The hot gas bypass is not a capacity control; it serves only to control surging at low loads thereby considered to be an operational control only.

SAFETY CONTROLS

Safety controls are provided to stop the centrifugal machine under any hazardous condition. The safety controls, see figure 80, are as follows:

1. Low oil pressure switch.
2. High condensing pressure cutout.
3. Low refrigerant temperature cutout.
4. Low chill water temperature cutout.
5. Chill water pump interlock.
6. Drum control interlock (optional).
7. Thermal overload cutout.

Low oil pressure may cause damage to the bearings and to the seal. High condensing pressure may result in overloading of the compressor, gears or motor and damage to the condenser. Low refrigerant temperature and low water temperature may freeze the water in the cooler tubes and result in tube rupture. The chilled water pump interlock prevents the machine from continuing to run after the start button is released. The drum control interlock prevents starting the motor unless all resistance is in the rotor circuit. The thermal overload cutout protects the control circuit.

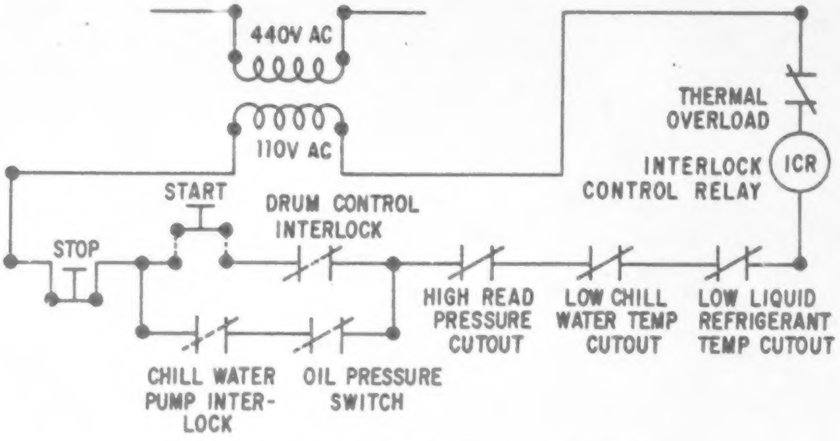
440V AC
110V AC
THERMAL OVERLOAD
INTERLOCK CONTROL RELAY
ICR
START
STOP
DRUM CONTROL INTERLOCK
HIGH READ PRESSURE CUTOUT
LOW CHILL WATER TEMP CUTOUT
LOW LIQUID REFRIGERANT TEMP CUTOUT
CHILL WATER PUMP INTER-LOCK
OIL PRESSURE SWITCH

Figure 80. Safety Control Circuit

Safety Control Operation

All the safety controls are automatic reset instruments. Each safety instrument operates a relay switch which has one normally open and one normally closed contactor. The only safety controls not considered to be automatic reset instruments are the chill water pump and drum control interlocks. These are manual starting units. When a safety instrument is in a safe position, the corresponding relay is energized and current is passed through the closed contactor. Should an unsafe condition exist, a safety control will deenergize the corresponding relay and the normally closed contactor will open to energize the circuit breaker trip circuit. When the circuit breaker trip circuit is energized, it trips open and stops the compressor motor. The oil safety switch operates somewhat differently. Since the oil pressure is not up to design conditions until the compressor comes up to speed, the relay for the oil pressure switch must be bypassed when the machine is started. The function of bypassing the relay for the oil safety switch is accomplished by a time delay relay in the circuit breaker, which keeps the trip circuit open until the compressor is up to speed. After a predetermined time interval, the time delay relay closes the trip circuit at the circuit breaker and the oil safety switch serves its function. If the oil pressure does not build up by the time the time delay relay closes, the trip circuit will be energized and the machine will stop. The low oil pressure switch cuts out at five pounds and in at six pounds. The high condensing pressure cuts out at 12 psi and in at eight psi. The low refrigerant temperature cuts out at 32°F and in at approximately 35°F. The low chill water temperature cuts out at 38°F and in at 45°F.

Control Circuit

The control circuit in figure 80 uses 110v ac as a power source. This control circuit is used to connect the various safety and operational control relays in such a manner as to allow current to flow through the circuit, thus protecting the system against hazardous conditions and allowing the starting of the machine.

The thermal overload, low liquid refrigerant temperature cutout, low chill water temperature cutout, high head pressure cutout, and the stop button are normally closed. These relays will open, stopping the machine, whenever a hazardous condition exists. Since the stop button is a manual control, it must be depressed by the operator.

Before starting the system, the operator must manually close the chill water pump interlock and place the handle on the drum controller in the OFF position, closing the drum control interlock. To start the system, the operator must manually depress the start button, thus creating a circuit through the thermal overload, interlock control relay, low liquid refrigerant temperature cutout, low chilled water temperature cutout, high head pressure cutout, drum control interlock, the start button, and the stop button.

Current will also flow through the chilled water pump interlock, and upon reaching the maximum oil pressure, the oil pressure switch will close. If after a twenty-second period, the oil pressure switch has not closed, release the start button and check your electrical circuit for possible troubles.

After the oil pressure switch has closed, and after the drum controller is placed in speed "1" or higher, the current will flow through the following: thermal overload interlock control relay, low liquid refrigerant temperature cutout, low chill water temperature cutout, high head pressure cutout, oil pressure switch, chilled water pump interlock and the stop button.

To stop the machine, whether normal or emergency operation, depress the stop button.

NOTE: The interlock control relay is energized by a magnetic coil that closes and allows current to flow to the holding coil of the main circuit breaker trip switch. Should the power be interrupted by any of the safety controls, the ICR (interlock control relay) will deenergize, tripping the main circuit breaker trip switch.

The discussion above on controls are of the basic type found on the 100-ton trainer here at Sheppard. A more detailed discussion of the control systems found on more modern machines will now be covered. It is very difficult to give definite instructions on specific types of controls. Each manufacturer uses various types, designs, and locations of controls. For the sake of our discussion, the Honeywell control system used on the Carrier Model 19D will be used for an understanding of control concepts.

Control Location and Function

BEARING HIGH TEMPERATURE CUTOUT. This is a safety thermostat located on the side of the compressor casting. The bulb of this thermostat is located in a trough cast in the compressor casting. It is an S. P. S. T. switch that opens on a rise in temperature. It senses the temperature of the oil after it flows through the thrust and transmission bearings. When the thermostat contacts open, they break the electrical circuit to the R-1 relay which stops the compressor. It will automatically reset itself when the temperature is lowered to its set point, but the machine will require manual restarting.

NOTE: Electrical diagrams showing the relays and electrical components will be discussed in a later unit covering electrical circuits.

OIL HEATER THERMOSTAT. This is the same type of control used for the Bearing High Temperature Cutout. It is located in the oil reservoir and its function is to control the power to the heater circuit. It is set to open the heater circuit when the desired temperature is reached. A yellow indicator light will be ON when the thermostat contacts are closed and the heater is ON.

PURGE SAFETY AND LABYRINTH GAS VALVE SWITCHES. This is a differential pressure switch located in the purge console. It senses the pressure difference between the cooler and condenser. The device has two functions, accomplished by two switches.

1. Purge safety switch--A normally open switch that closes on an increase in pressure differential. Its contacts are connected in the automatic purge circuit and will not allow the purge to operate until the machine is started and there has been a pressure difference established between the cooler and condenser. It is set to close at 8 psid and open at 6 psid.

2. Labyrinth gas valve switch--A normally closed switch that opens on an increase in pressure differential. Its contacts are connected in the labyrinth gas solenoid valve circuit and will be closed any time the pressure difference between the cooler and condenser is below 10 psi. When the pressure difference increases above this, the switch opens and deenergizes the labyrinth gas solenoid. It is factory set to open at 10 psid and close at 8 psid.

PURGE OPERATING SWITCH. This is also a differential pressure switch located in the purge console. It senses the pressure difference between the condenser and purge collection chamber. It is an S. P. S. T. normally-closed switch and will open on an increase in differential pressure. Its contacts are connected in the purge automatic circuit in series with the purge safety switch. As noncondensables are collected in the purge collection chamber the pressure in that chamber will rise. This decreases the pressure difference between the condenser and purge. At 2 psid, this switch will close and the purge compressor will operate until the noncondensables are removed and the pressure difference is 4 psid.

CONDENSER HIGH PRESSURE CUTOUT. This is a safety control and is a pressure-operated S. P. S. T. switch that opens on a rise in pressure. It is a manual reset device. It is mounted in the control console and is connected by copper tubing to a pressure tap in the condenser. On a pressure rise, the electrical contacts open the R-1 circuit and will require manual reset of the control plus manual restart of the machine.

ANTIRECYCLE TIMER. This is an adjustable timer located in the console. It has a switch with two sets of contacts. They close instantaneously when power is applied and open at the end of the time period set on the dial. It limits the number of starts of the compressor to 3 per hour. The time range is adjustable from zero to 30 minutes with a minimum of 3 minutes. Each dial mark equals 2 minutes. The timer is factory set at 20 minutes.

REFRIGERANT LOW TEMPERATURE CUTOUT. This is a safety switch mounted in the console with the remote bulb located in a section of the float chamber which is open to the cooler. A thermometer is also located in this chamber. It is an S. P. S. T. switch with the contacts located in the control cirucit to relay R-1. Its purpose is to shut down the compressor at a preset point and prevent freezeup of the chilled water. It is necessary to push the start button to restart the compressor if it has shut down on this control.

LOW OIL PRESSURE CUTOUT. This is a pressure differential switch with a normally open contact located in the pressure switchbox on the front of the compressor. The high pressure connection is connected to the oil line to the motor end bearing. The low pressure connection is connected to the oil reservoir. The switch will close when sufficient oil pressure is established. If for any reason, this pressure drops below the set point, the contacts will open and break the circuit to coil ICR. This will shut down the compressor but the oil pump will continue to operate. When sufficient pressure has been reestablished, ,the compressor will restart again. However, at this time the antirecycle timer is energized and if the oil pressure cutout opens again, the compressor and oil pump will stop and will not restart. This switch is factory set to close at 16 to 17 psi and open at 11 to 12 psi above the oil reservoir pressure.

OIL FILTER HIGH PRESSURE CUTOUT. It is a differential pressure switch with the high pressure side connected in the oil circuit between the cooling coil and filter. The low pressure side is connected after the filter at the same point as the high pressure connection of the low oil pressure cutout. The switching action is the reverse of the low oil pressure switch and the control will open on an increase in differential pressure. The switch is a manual reset device and the compressor will not automatically restart.

The oil filter switch is installed on machines with shipment dates up to 15 June 1965.

VANE CLOSED SWITCH. The vane closed switch is an integral part of the guide vane motor. Its purpose is to insure that the compressor can start only when the inlet guide vanes are in the CLOSED position. The switch contacts are closed when the inlet guide vanes are closed and are OPEN when the guide vane motor has rotated 9 degrees (± 3) from its normal CLOSED position. The closed position is 15 degrees (± 3) from the vertical centerline. Therefore, we can say the vane closed switch opens when the crankarm is at a 24 degree angle from the vertical centerline. At this time the switch is electrically bypassed by a contact on the ICR relay which is located in the motor starter.

REFRIGERANT AGITATOR SWITCH(s). The refrigerant agitator switch(s) are located in an accessory package which attaches to the guide vane motor. Their purpose is to energize the refrigerant agitator solenoid valves at a predetermined vane position. The switch contacts are closed and the solenoid valves are open when the guide vane motor is in the closed position. These switches are set to open after nine degrees and 27 degrees of vane motor rotation when two agitator valves are used and at 27 degrees when one valve is used.

CHILLED WATER LOW TEMPERATURE CUTOUT AND RECYCLE SWITCH. This thermostat is used as an operational and safety control. It is located on the end of the unishell at the chilled water outlet. The bulb is located in a tube in the bottom row of the outlet pass. It is an S. P. S. T. switch that opens on a fall in temperature and has an adjustable differential. The switch contacts are in the ICR circuit and will recycle the machine off and on automatically as required by the chilled water load. Recommended setting is to cut out 5°F below leaving chilled water or 36°F whichever is higher. Cut in at 10°F above cutout point.

MOTOR WINDING HIGH TEMPERATURE CUTOUT. This is a bimetallic type thermostat which is imbedded in the motor windings at the three o'clock position when viewed from the compressor end. Its purpose is to shut down the compressor when the motor windings become overheated. This will prevent a motor burnout. The switch contacts are normally closed and will open when the winding temperature rises to a predetermined point. They will not close until the temperature falls below a predetermined point. These settings are nonadjustable and are factory set.

REFRIGERANT PUMP THERMOSTAT. This is also a bimetallic thermostat located at the same point on the motor winding as the motor winding thermostat. Under certain light load conditions, the pressure difference between the motor compartment and the condenser is not enough to provide liquid refrigerant to the motor for cooling. When this occurs, the motor winding temperature rises. At a predetermined temperature (below that of the motor winding high temperature cutout setting), the normally open contacts of the refrigerant pump thermostat will close and start the refrigerant pump. When the windings cool to a predetermined set point, the contacts will open stopping the pump. This thermostat is also factory set and is nonadjustable.

CHILLED WATER CONTROL ELEMENT (ELECTRONIC). The chilled water control element is located in the outlet of the chilled water circuit. It is a resistance-type element and has no moving parts. It requires no adjustments. Electronic controls will be discussed in a later unit of study.

Now that we have discussed some of the controls found on the 19D machine, we shall place them into electrical control circuitry. You cannot hope to work effectively on a machine if you do not understand:

1. What the circuit is supposed to do in normal operation, and how to operate it.
2. What each piece of equipment in the circuit does and how it functions.
3. The location of each part and the routing of the wiring.
4. The most likely cause of any malfunction.
5. The best place for making a circuit test.

To make it easier to understand, we will use "schematic diagrams" or, as they are often referred to, a one-line diagram and build the circuits for our machine. It is important to remember, the contacts and controls are shown in their--normal--ready to start--position.

CONTROL SYSTEM WIRING SCHEMATICS

The wiring diagrams shown in figures 81 through 91 are typical complex control system wiring schematics. Using this type of wiring schematic makes it easier to follow and/or isolate the individual circuits. Isolating the circuits makes it easier to analyze the circuit operation and its relation to the other circuits of the control system. The circuits diagrammed in figures 81 through 91, the contacts and controls are shown in the normal READY TO START POSITION.

The basic structure of the diagrams (figures 81 through 91) is the powerlines that run vertically down the two sides of the diagrams. In this case, the powerline on the left has a voltage of 115 volts while the powerline on the right is neutral in potential. The "grounding arrow" on the upper right of the neutral power wire indicates that the neutral wire of the control system is grounded intentionally. The operating voltage of the control system that is to be discussed is 115 volts. All of the control circuits that are shown constructed between the power wires operate as 115-volt circuits in parallel.

Start and Stop Circuits

Figure 81 shows circuits that will start and stop the centrifugal machine along with some auxiliary equipment such as the chilled water pump, condenser water pump, and cooling tower fan. To explain the control circuit, we will follow the operation step by step.

The "Red Indicator Light", when energized, tells us that the control circuit has power available. When the start button is pressed, it energizes a relay coil, labeled as R1, and a green indicator lamp which indicates relay R1 has power. When the relay R1 has operated, one of its contacts will open the circuit to the red indicator lamp which indicates that the R1 contacts have been actuated. Another contact of relay R1 closes and bypassed around the start button to maintain power to the relay coil. Another R1 contact, located in series with the compressor control relay coil, also closes. The control relay depends on several other switches being closed before it can operate. If those control contacts are closed, the control relay will allow the compressor to be started. The compressor VANE CLOSED switch must be closed to allow power to the control relay coil (1CR) but will only be closed if the compressor capacity control vanes are in the closed position. When the vane switch is closed, the control relay will be energized and close the compressor motor contacts. The control relay (1CR) closes one of its contacts to bypass the VANE CLOSED switch so that the vanes can now open without affecting the control relay circuit.

The auxiliary equipment is energized at the same time as the start was pressed. When the start button was pressed, the PILOT RELAY (PR) coil was energized. The PILOT RELAY closed contacts which feeds power to the chilled water pump, condenser water pump, and the cooling tower fan. It will be shown later that the auxiliary equipment must be operating before the compressor will run. While the start button is still

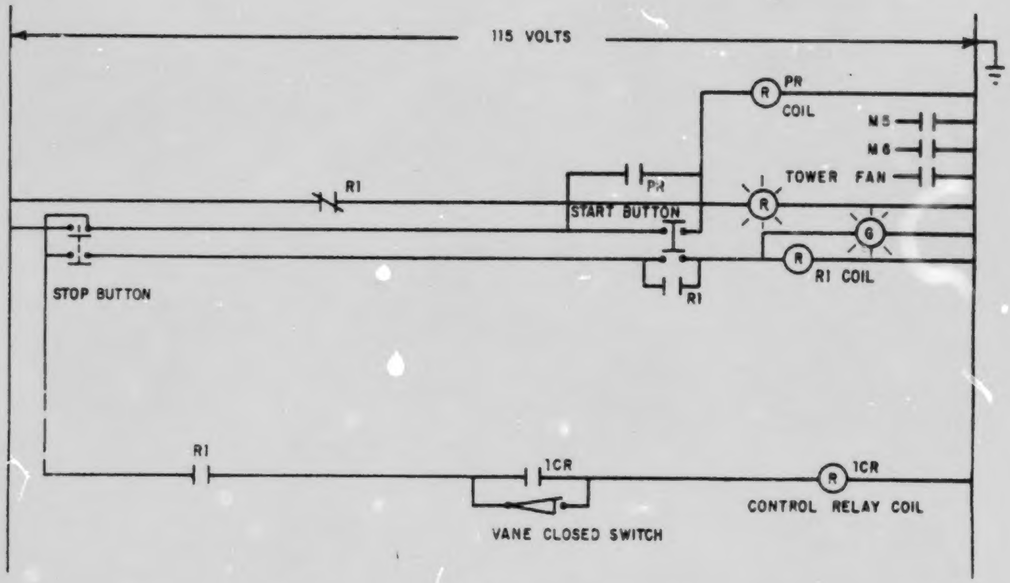

Figure 81. Start and Stop Circuits

depressed, the PILOT RELAY also closes contact PR which bypasses the start switch in order to maintain power to the relay coil after the start button is released.

To stop the compressor and auxiliary equipment, all that is required is to press the "Stop Button" which opens the power supply to the relay coils and contacts of the control circuits.

Oil Pump Motor Control Circuit

The schematic in figure 82 is the same as figure 81 except for the addition of the oil pump motor control circuit, which is shown at the top of the schematic in heavy lines. The schematic shows that the oil pump may be operated manually or automatically, depending only on the position of the selector switch. The selector switch is spring-loaded to the automatic position; therefore, to manually operate the oil pump, the selector must be held in the manual position by the operator. Normally, as in the automatic position, the oil pump must be operating and producing pressure before the compressor can be energized. The circuits which assure oil pump operation before the compressor can be started will be shown in figure 84. Regardless of the selector switch position, the oil pump motor can only operate if the pump motor line starter coil can be electrically energized. Notice that the pump line starter coil, labeled M3, has two overload contacts that must be closed before that coil can be energized. If the overload contacts are closed, the pump motor will start.

When the oil pump line starter coil was energized, it started the oil pump to produce oil pressure for lubrication prior to compressor startup. The compressor starting circuit cannot be energized before the pump is producing pressure, due to the oil pressure cutout switch in the starting circuit. There is also a magnetically operated switch in the compressor starting circuit which depends on oil pump motor

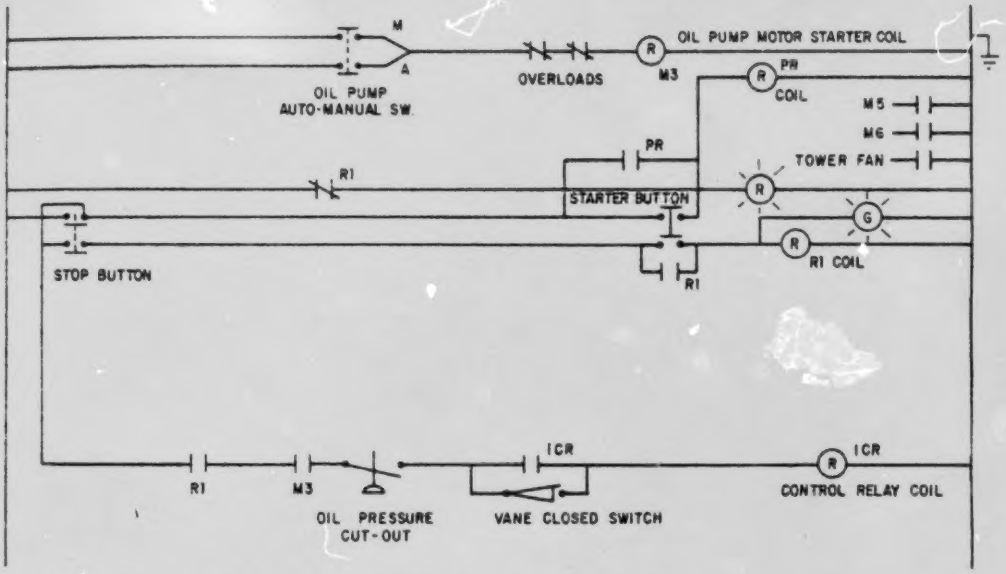
M
A
OIL PUMP
AUTO-MANUAL SW.
OVERLOADS
R
M3
OIL PUMP MOTOR STARTER COIL
R
PR
COIL
M5
M6
TOWER FAN
PR
R1
STARTER BUTTON
R
G
R
R1 COIL
STOP BUTTON
R1
R1
M3
OIL PRESSURE
CUT-OUT
ICR
VANE CLOSED SWITCH
R
ICR
CONTROL RELAY COIL

Figure 82. Oil Pump Motor Control Circuit

operation or at least on the pump starter operation. The oil pump line starter, operated by coil M3, closes the auxiliary contact in the line starter which then feeds power to the oil pressure cutout switch. When the pump has built up oil pressure, the oil pressure cutout switch will close and the compressor control relay (1CR) will be energized, if the "Vane Closed" switch is closed, and thus start only the compressor.

Motor Cooling Pump Circuit

In figure 83, starting at the top is the motor cooling pump. This is the pump that provides liquid refrigerant to the motor for cooling purposes under certain previously mentioned operating conditions. It is controlled by a thermostat which senses the temperature of the motor windings, when the motor windings reach a predetermined temperature, the thermostat contacts will close and the motor cooling pump will start. The green indicator light will come on. When the windings cool to a predetermined temperature, the thermostat contacts will open and the motor cooling pump stops. The manual switch is connected in parallel with the thermostat and is used only to operate the pump manually.

Purge Pump Circuit

The next circuit down the diagram is the purge pump circuit. The switch at the left is for manual or automatic operation. When at contact M the purge pump motor (PPM) will operate, the purge solenoid will open and the yellow indicator light will come on. This switch is placed in A for automatic, normal operation.

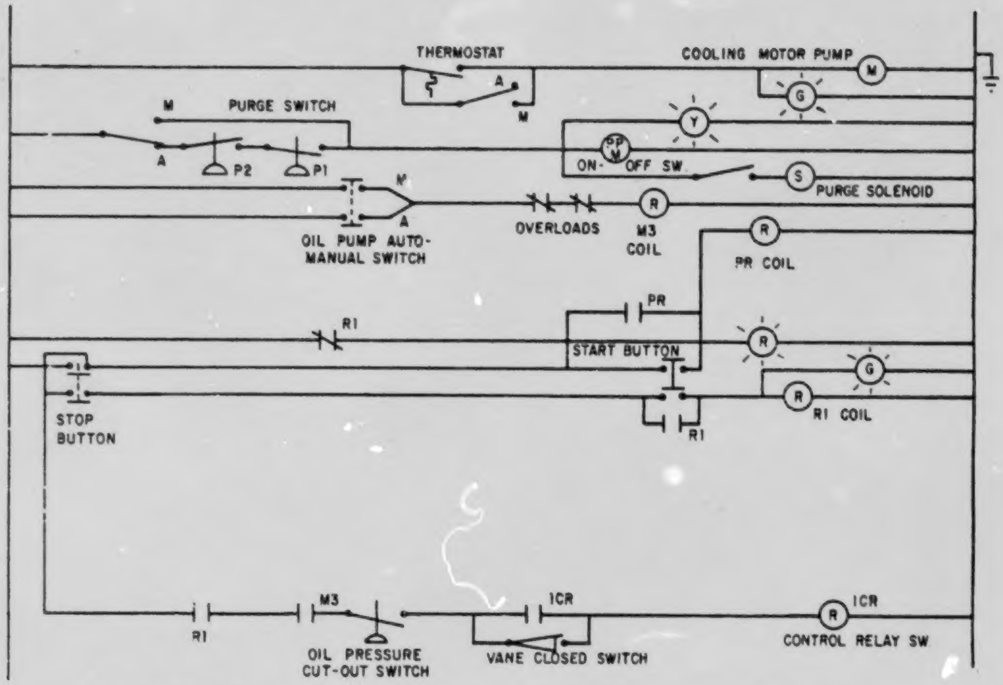
THERMOSTAT
COOLING MOTOR PUMP
M
A
M
PURGE SWITCH
M
A
P2
P1
Y
G
SP M
ON-
OFF SW
S
PURGE SOLENOID
M
A
OIL PUMP AUTO-MANUAL SWITCH
OVERLOADS
R
M3 COIL
R
PR COIL
PR
R1
START BUTTON
R
G
R
R1 COIL
R1
STOP BUTTON
R1
M3
OIL PRESSURE CUT-OUT SWITCH
1CR
VANE CLOSED SWITCH
R
1CR
CONTROL RELAY SW

Figure 83. Motor Cooling Pump and Purge Pump Circuits

Switches P-1 and P-2 are pressure differential switches. P-1 is the purge safety switch and is connected across the cooler and condenser. When the difference across these two components is greater than 8 psi, the switch will close. This occurs shortly after startup. Switch P-2 is called the purge operating switch and is connected across the main condenser and the purge condenser. When noncondensables accumulate in the purge condenser, the pressure increases. This closes the P-2 contact and the purge pump will operate until the pressure is reduced.

When it is necessary to operate the purge manually, the purge switch is placed in the M position. An ON-OFF switch is also located in the purge solenoid control circuit. Place this switch in the ON position for normal operation.

Compressor Lubrication Circuit

The moving parts of a centrifugal compressor normally operate at a very high RPM. Lubrication of the compressor is of the utmost importance to the operation of the machine. Lubrication of the compressor, preceding compressor startup, is assured by a time-delay relay coil, which will close the delay contacts to start the oil pump motor. In other words, when the compressor start button is pressed and the relay, R1, (see figure 84), has operated its contacts, one set of contacts (R1 contacts) closes and feeds power to the time delay relay coil which then closes the contacts, in the pump motor control circuit, to start the pump motor. The compressor control relay cannot be energized until the pump is running and producing pressure. Thus the compressor cannot be started without proper lubrication being available.

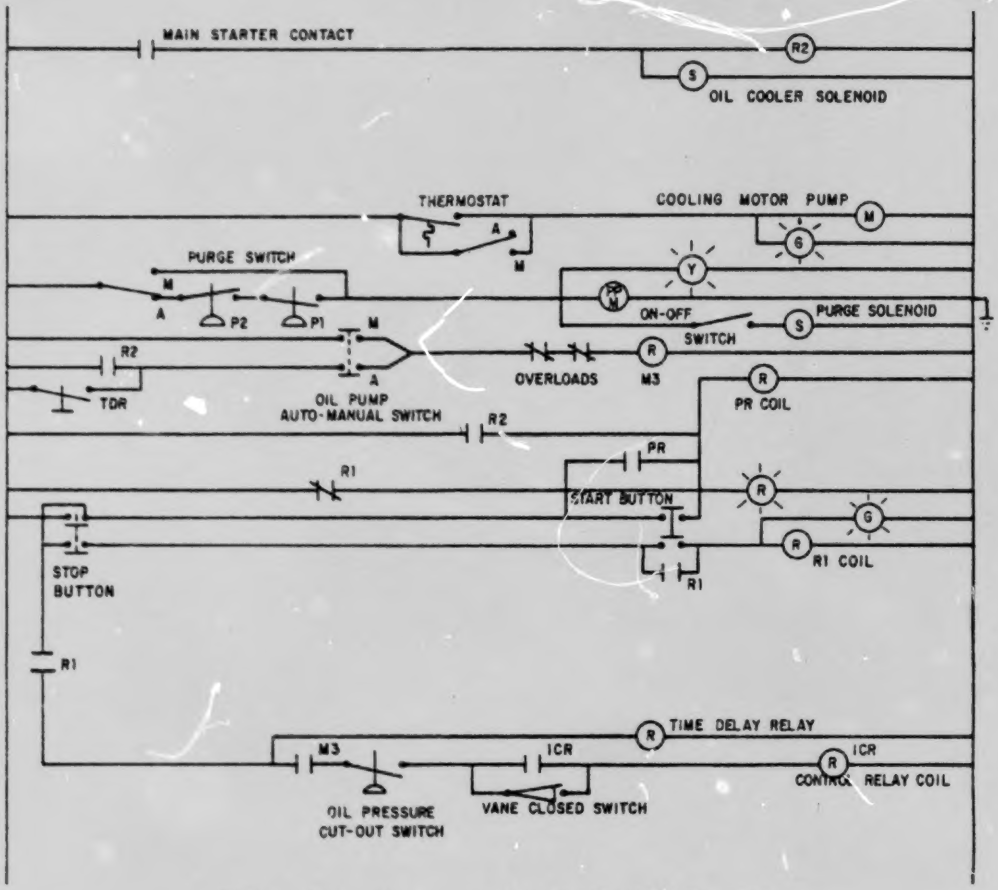
MAIN STARTER CONTACT
R2
S
OIL COOLER SOLENOID
THERMOSTAT
A
M
COOLING MOTOR PUMP
M
G
PURGE SWITCH
M
A
P2
P1
Y
PPM
ON-OFF SWITCH
S
PURGE SOLENOID
R2
M
A
TDR
OVERLOADS
R
M3
OIL PUMP AUTO-MANUAL SWITCH
R2
R
PR COIL
PR
R1
R
START BUTTON
G
R
R1 COIL
R1
STOP BUTTON
R1
R
TIME DELAY RELAY
M3
ICR
R
ICR
CONTROL RELAY COIL
OIL PRESSURE CUT-OUT SWITCH
VANE CLOSED SWITCH

Figure 84. Compressor Lubrication Circuit

As can be seen, the machine can operate in an automatic mode because of the oil pump circuit which provides lubrication to the compressor prior to startup. When the compressor is shut down for any reason, it still needs lubrication during the coast-down period of the machine. The only time the oil pump will not provide oil pressure for operation or coast-down is if the oil pump or motor failed. Unless there is a failure in the oil pump or motor, the time delay relay will maintain oil pump operation by holding the delay contacts closed for approximately one minute after compressor shutdown.

If the compressor contacts should ever weld or otherwise get stuck in the closed position, in spite of the control circuit trying to shut the compressor down, there must be a circuit which will keep the oil pump running. There is such a circuit in this diagram. Tied in with this circuit is a relay (R2), which not only keeps the oil pump operating but also maintains the power to the pilot relay coil which keeps the auxiliary equipment running to prevent chilled water freezeup and excessive head. The circuit operates as follows. When the compressor has started and reached its running speed, the motor will be connected to the power through a line starter which provides delta connections. As the delta connected starter closes, it also closes an auxiliary contact which feeds power to the oil cooler solenoid and relay Coil R2. Relay contacts of R2 closes two circuits. One of the contacts will bypass the pump motor time-delay contacts to keep the pump operating. The other R2 contacts will maintain power to the pilot relay to keep the chilled water pump and condenser water pump operating. Notice that the oil cooler solenoid will be energized any time that the compressor is in operation.

Indicator Lights

In figure 85, lights and solenoid valves have now been added in the lower right corner of the diagram. The green light is the low oil pressure indicator. It will be lit whenever there is sufficient oil pressure to keep the oil pressure cutout closed. If the compressor should shut down on low oil pressure safety switch, this light will be OFF.

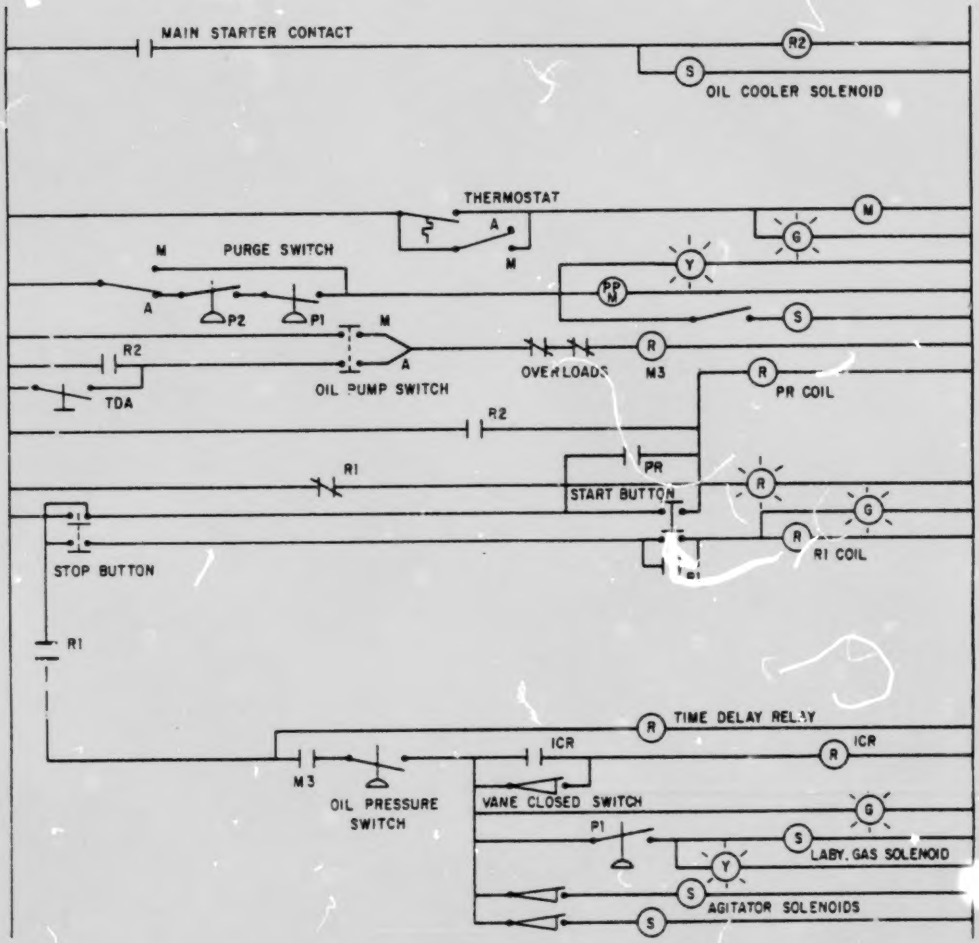
MAIN STARTER CONTACT
R2
S
OIL COOLER SOLENOID
THERMOSTAT
A
M
M
G
M
PURGE SWITCH
Y
A
P2
P1
PP M
S
M
R2
A
OIL PUMP SWITCH
OVERLOADS
R
M3
TDA
R
PR COIL
R2
PR
R1
START BUTTON
R
G
R
R1 COIL
STOP BUTTON
R1
R
TIME DELAY RELAY
ICR
R
ICR
M3
OIL PRESSURE SWITCH
VANE CLOSED SWITCH
G
P1
S
LABY. GAS SOLENOID
Y
S
AGITATOR SOLENOIDS
S

Figure 85. Indicator Lights

The next step down shows a normally closed pressure switch (P-1), the labyrinth gas solenoid valve and a yellow indicator light. P-1 switch is a pressure differential switch connected across the cooler and condenser. When this pressure rises to 10 psi the switch will open and the solenoid valve will close. As the machine load and condenser pressure decrease, the pressure differential will decrease and at 8 psi the switch will close and the solenoid valve will be energized. The yellow indicator light will be ON whenever the solenoid is energized.

The next two steps down show two normally closed switches and two more solenoid valves. The switches are enclosed in the guide vane actuator and are operated by a cam connected to the actuator shaft. When the load decreases and the vane actuator rotates, these switches will close at preset conditions and open the solenoid valves in the agitation lines.

Capacity Control

In the preceding diagrams the machine would operate properly if it was always at full load conditions. When a changing load is imposed on the machine some means must be provided to control the capacity of the machine. This has been added in figure 86.

The chilled water control element is shown in the lower left corner. This is a resistance element which is located in the leaving chilled waterline. As the water temperature changes, a signal is sent to an amplifier circuit in the chilled water control unit which causes a relay to operate the guide vane actuator. It rotates in the proper direction and moves the guide vanes. As they open or close the capacity of the machine is increased or decreased. The two wires extending from bottom of the chilled water control lead to a current transformer in the main motor starter which controls the guide vane actuator in the event of motor overload.

One side of the control is connected to the Electronic Control ON-OFF switch in the hot line ahead of the stop button. It is recommended that this switch be kept ON during the cooling season. This will always keep the electronic components warm. If the power to these components was cut off each time the machine stopped, the components would be subjected to alternate heating and cooling and their life greatly reduced.

The electronic control circuit will be discussed in a later unit of instruction.

Antirecycle Control

In figure 87, the components now added to the control circuit are all part of the antirecycle control. If the machine were to operate normally with less than 3 starts per hour, there would be no need for these components. They are safety devices placed in the circuit to protect the motor from short cycle starting.

Under normal starting conditions, relay 2CR is energized when the start button is pushed and contacts R-1 and M-3 in the hot line are closed. This action closes the N. O. contact and opens the N. C. contact in the hot line to the relay R5 shown at the upper left. R5 relay is deenergized so the N. C. contact (R-5) in the hot line to relay 1CR does not open and 1CR remains energized. At the same time coils TM (timer motor), TC (timer clutch), and relay R-6 are energized. Contacts T are N. C. and set for a 20-minute delayed opening action. After this delay period T contacts open and do not close until TC is

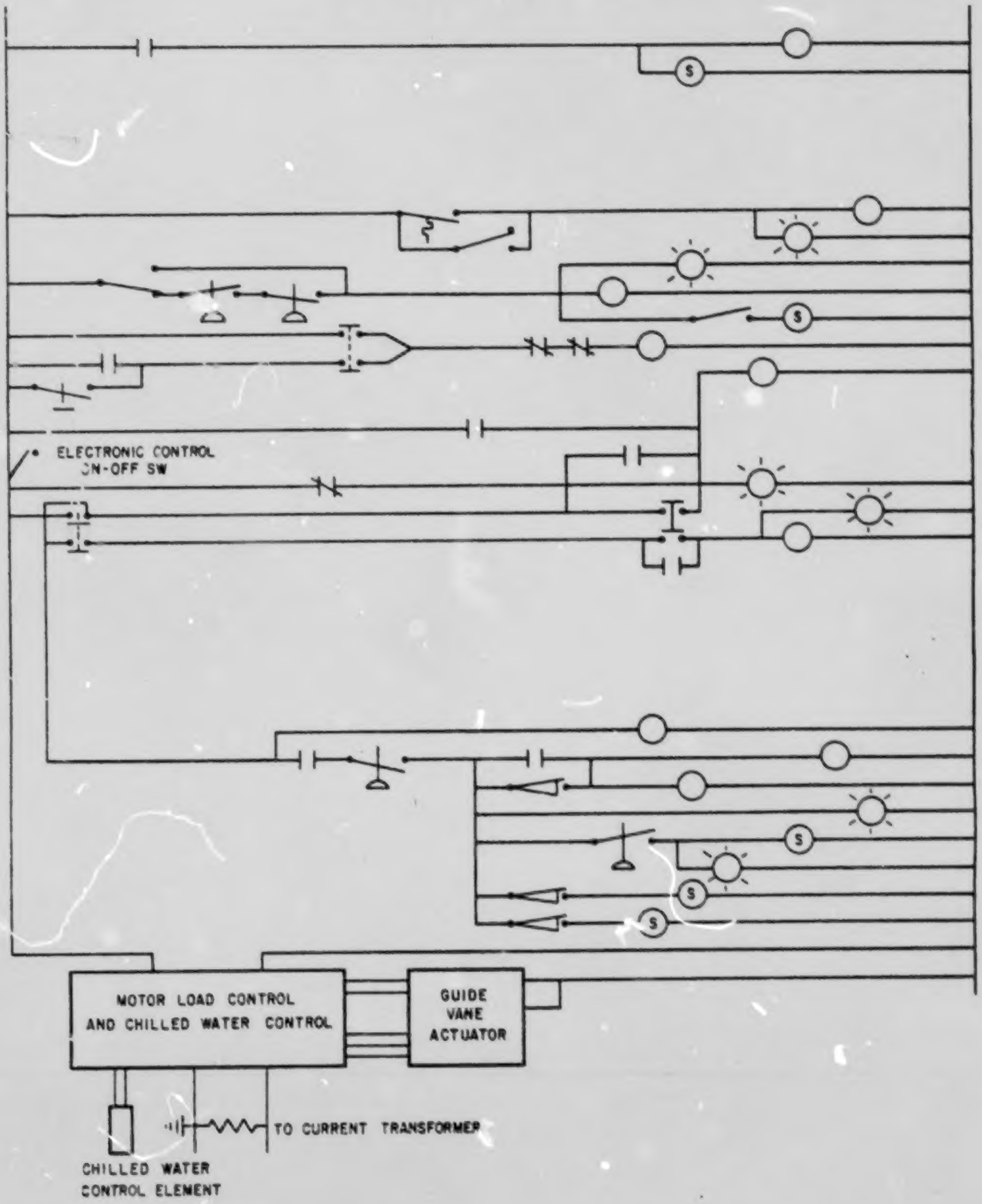
S
ELECTRONIC CONTROL
ON-OFF SW
MOTOR LOAD CONTROL
AND CHILLED WATER CONTROL
GUIDE
VANE
ACTUATOR
TO CURRENT TRANSFORMER
CHILLED WATER
CONTROL ELEMENT

Figure 86. Capacity Control

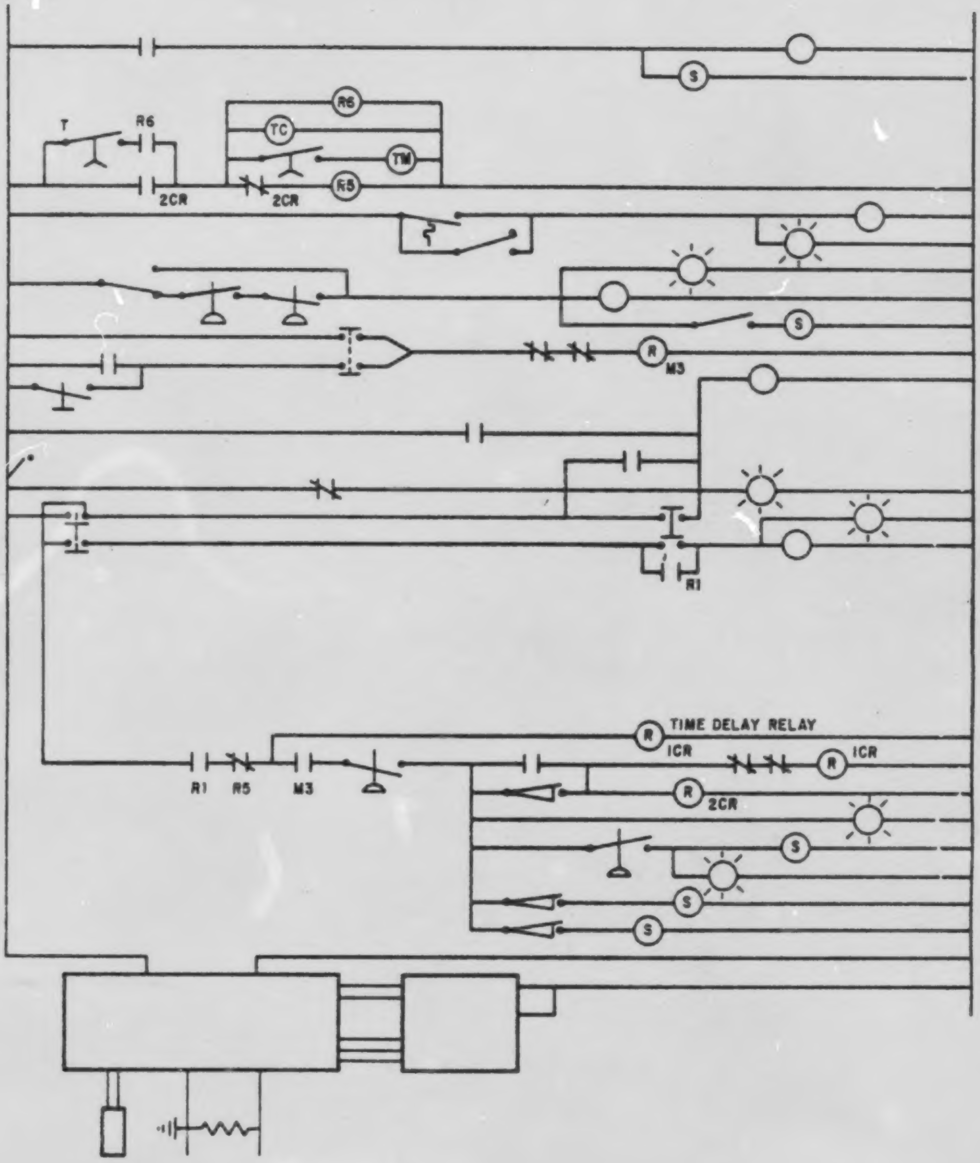
S
T
R6
R6
TC
TM
2CR
2CR
R5
S
R
M3
R1
R
TIME DELAY RELAY
ICR
R
ICR
R1
R5
M3
R
2CR
S
S
S

Figure 87. Antirecycle Control

deenergized. Under normal conditions this break of the T contacts have no effect because the circuit is complete through contact 2CR. Therefore, the machine will continue to operate normally.

If the machine stops for any reason within 20 minutes after startup, relay 2CR will be deenergized. This would return contacts 2CR to their normal positions. The circuit would then be complete through the left-hand T contact, contact R-6 and NC contact 2CR to relay R-5. When R-5 is energized it opens the N.C. contact (R-5) in the line to 1CR and 1CR cannot be energized. The compressor cannot operate if 1CR is not energized.

After the timer motor has run through its 20-minute period, the T contacts will open and deenergize relays R-5 and R-6 and coils TM and TC. Contact R-5 will close. Contact R-6 will open and keep relay R-5 deenergized. The machine can now be restarted.

Protective Devices

In figure 88 we will add fuses, safety controls, and interlocking contacts.

In the third step down, a 3-amp fuse has been placed in the hot line to protect the motor cooling pump. In the fourth step down a 15-amp fuse has been added in the purge pump circuit. Another 3-amp fuse has been added just to the right of the stop button. This is for the protection of R-1 and the safety devices in that circuit.

The safety devices in this circuit are numbered 1 through 4 and M5 and M6. Number 1 is the condenser high pressure cutout. It is a normally-closed switch with manual reset. If the condenser pressure should rise above the set point of 15 psig, the contacts will open the circuit to R-1 and stop the machine. To retart, manually reset the control and push the start button.

Number 2 is the bearing high temperature cutout. It senses the temperature of the oil as it leaves the transmission. If this temperature exceeds 185°F, the contacts will open and stop the compressor. To restart, push the start button.

Number 3 is the motor high temperature cutout. It is a nonadjustable thermostat which senses the motor winding temperature. When the windings reach a temperature of 221°F (± 10) the switch will open and stop the compressor. To restart, wait until the windings cool and push the start button.

Number 4 is the refrigerant low temperature cutout. It is set to shut down the compressor when the refrigerant temperature reaches 1°F below the design suction temperature or 34°F, whichever is the lower. To restart, wait for the refrigerant temperature to rise and push the start button.

Contacts M5 and M6 are auxiliary contacts in the starters for the chilled water and condenser water pumps. If either of these starters open, the circuit is broken to R-1 and the compressor stops. On systems using flow switches they are connected in the same line. To restart in either case, push the restart button.

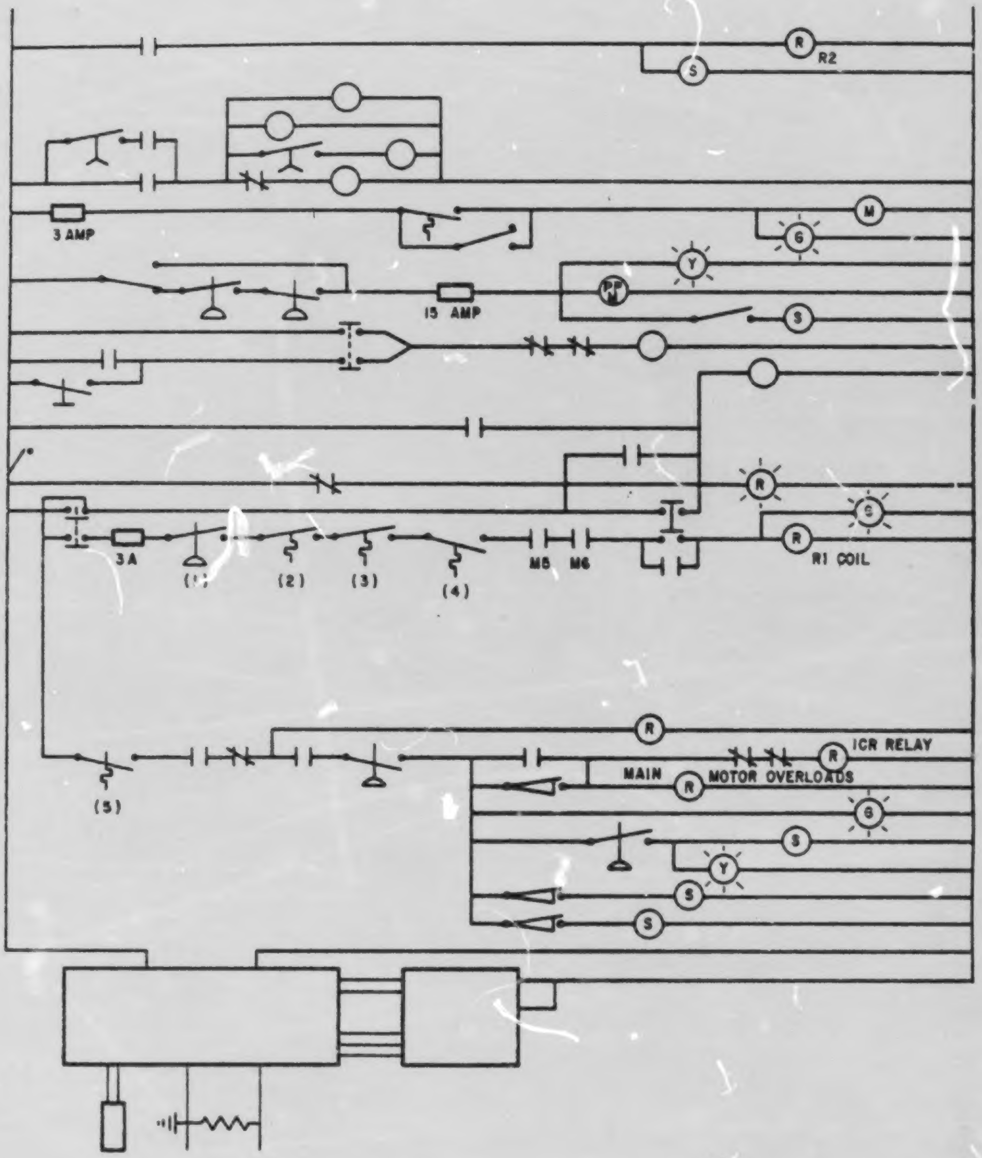
R
R2
S
3 AMP
M
G
Y
PP M
15 AMP
S
R
S
R
R1 COIL
3A
(1)
(2)
(3)
(4)
M5
M6
(5)
R
ICR RELAY
MAIN
R
MOTOR OVERLOADS
G
S
Y
S
S

Figure 88. Protective Devices

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The next step down the diagram is a normally closed thermostat labeled as number 5. This is the chilled water temperature cutout and recycle switch. It senses the leaving chilled water temperature and shuts down the compressor when the leaving chilled water temperature falls to 5°F below the design chilled water temperature. When the chilled water temperature rises approximately 10°F the switch will close and the compressor will restart automatically. This can be classified as an operating control. It differs from the previously described controls in that when its contacts remake the compressor starts automatically.

Do not confuse this control with the chilled water element control we discussed in figure 86. The control element sends a signal to the guide vane actuator which opens and closes the guide vanes and regulates the capacity of the machine. The low chilled water temperature cutout and recycle switch will start or stop the machine and functions only when the chilled water temperature drops below the set point of the control element.

The N. C. contacts added to the line to relay 1CR are the main motor overloads. When the power drawn by the motor exceeds the set point, these contacts will open and stop the compressor. For safety reasons, you should push the stop button prior to resetting the overloads. If not, the compressor will start when the overloads are reset.

If any of the abovementioned contacts open, the chilled water and condensing water pumps will continue to operate. The only time they will stop is when the stop button is pushed and R-2 is deenergized.

Normal Operation Indicator Lights

To figure 89, we have added five green indicator lights. They are located on the front of the control panel. When the machine is operating normally all of these lights will be ON.

Number 1 is the chilled water temperature light. When the compressor stops on the chilled water low temperature cutout and recycle switch this light will go off. The others will remain ON.

Number 2 is the condenser pressure indicator. When the condenser high pressure cutout opens, this light and lights 3, 4, and 5 will go out.

Number 3 is the bearing and motor winding high temperature indicator. When these safety cutouts open, this light and lights 4 and 5 will go out.

Number 4 is the low refrigerant temperature indicator. When the refrigerant low temperature cutout opens, this light and number 5 will go out.

Number 5 is the waterflow indicator. If the M5 or M6 contacts open or if flow switches are used and they open, this light will go out.

If the main starter overloads open, all the green lights will remain on.

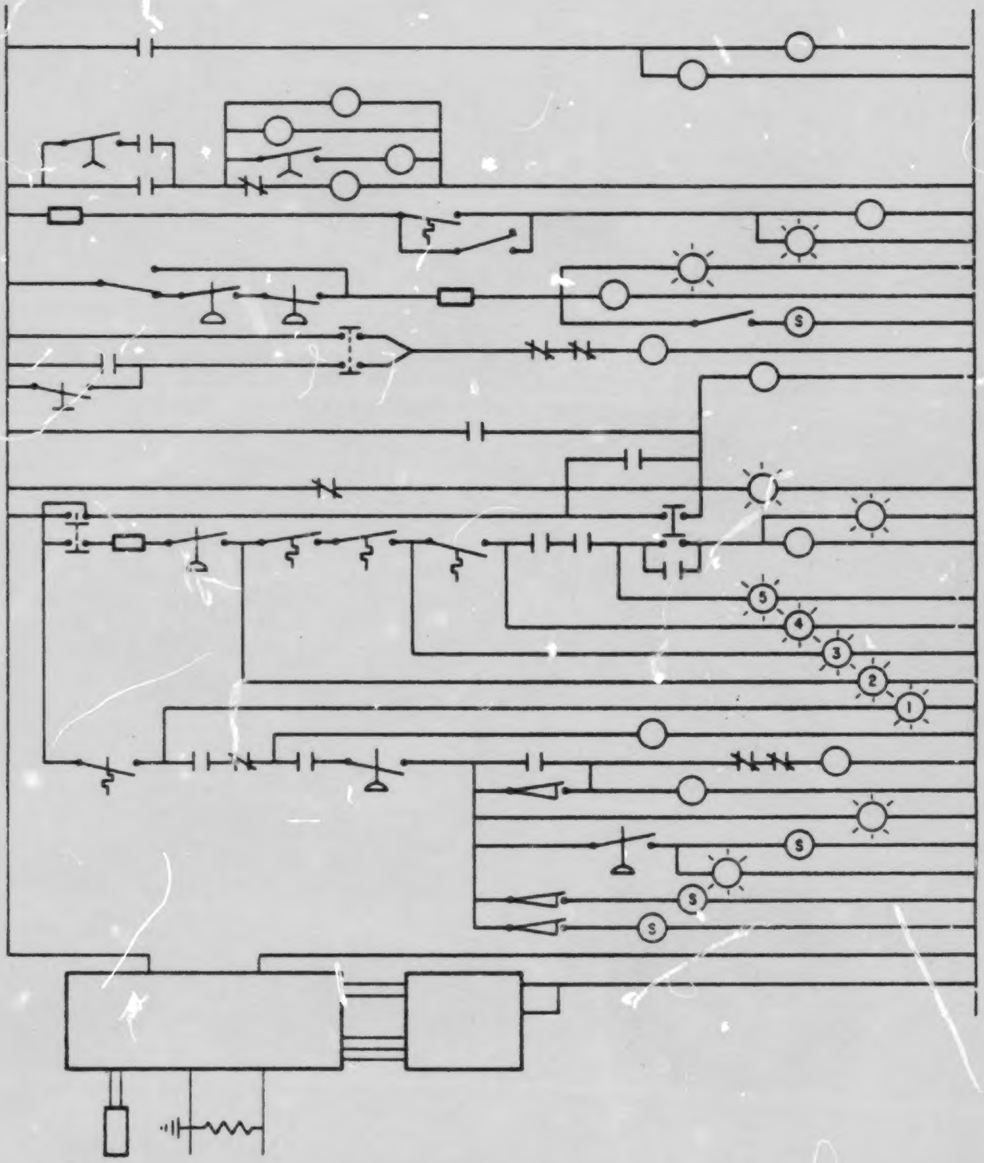

Figure 89. Normal Operation Indicator Lights

Oil Heater and Thermostat

To minimize the amount of refrigerant which is absorbed in the oil, it is necessary to keep the oil warm. To accomplish this an oil heater and thermostat are used. Both are submerged in the oil reservoir. The thermostat is set to open when the desired oil temperature is reached. This breaks the circuit to the heater and turns it off.

The source of voltage is from a circuit separate from the control circuit. In this manner, the heater and thermostat are not removed from use when the control circuit is turned off.

A yellow light is connected in parallel with the heater to indicate when it is on. A 15-amp fuse is also installed ahead of the thermostat to protect the circuit in case of overload. (See figure 90)

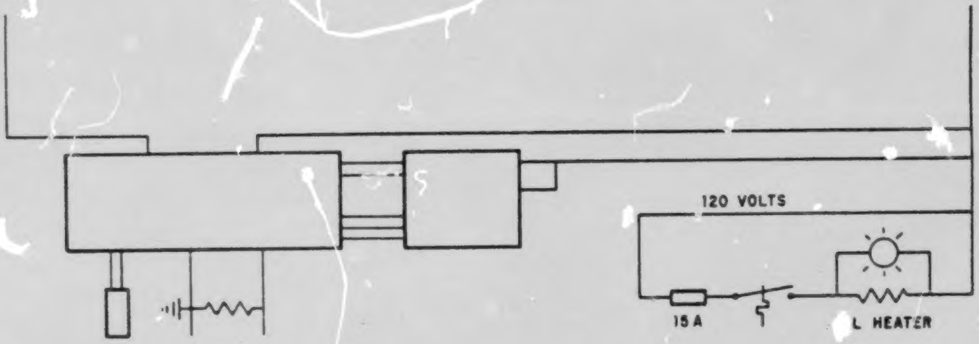

Figure 90. Oil Heater and Thermostat

Figure 91 is the complete wiring diagram with all components labeled.

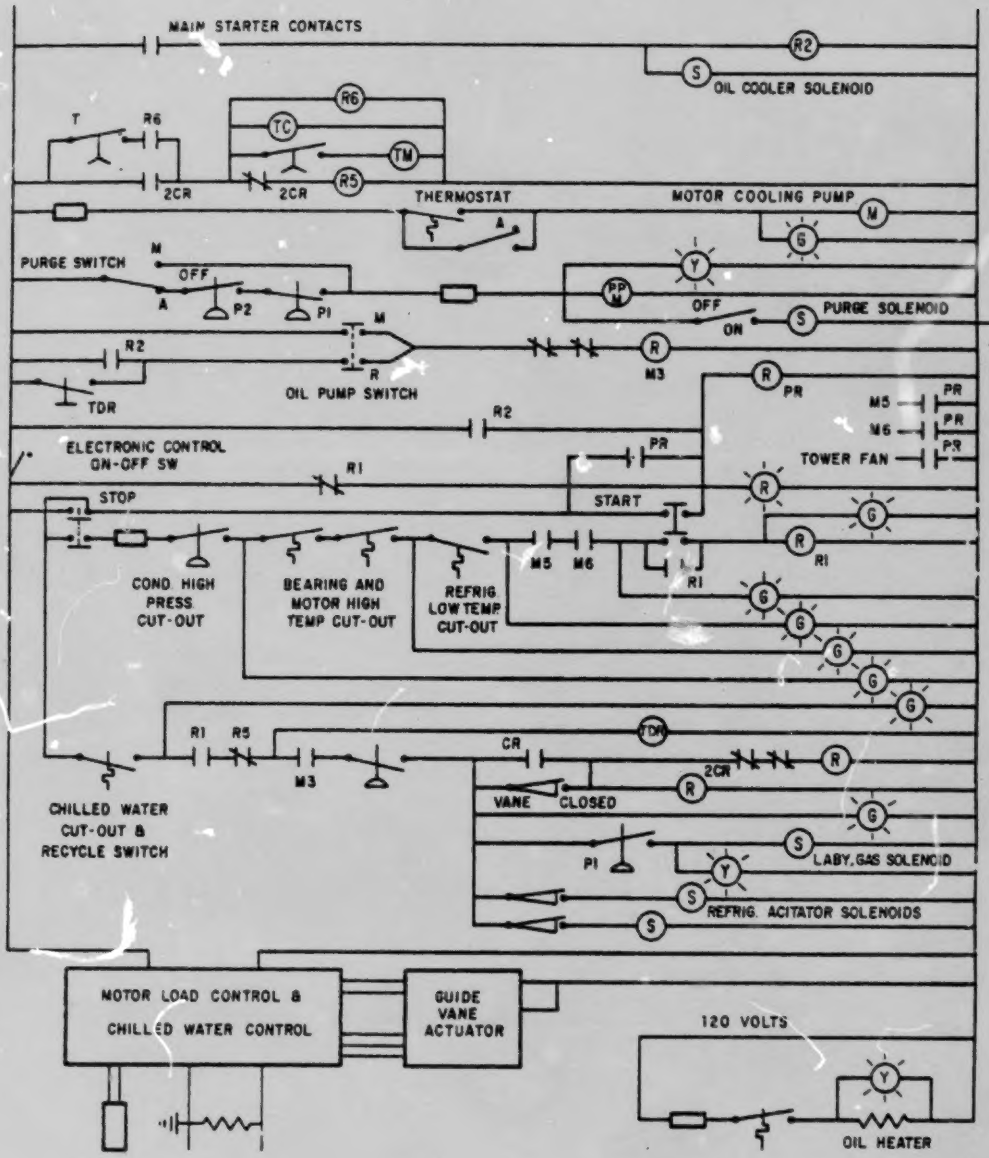
MAIN STARTER CONTACTS
R2
S
OIL COOLER SOLENOID
R6
T
R6
TC
TM
2CR
2CR
R5
THERMOSTAT
A
MOTOR COOLING PUMP
M
G
PURGE SWITCH
M
OFF
A
P2
P1
Y
PP M
OFF
ON
S
PURGE SOLENOID
M
R2
R
TDR
OIL PUMP SWITCH
R
M3
R
PR
M5
PR
M6
PR
TOWER FAN
PR
R2
ELECTRONIC CONTROL
ON-OFF SW
PR
R1
R
STOP
START
G
R
R1
M5
M6
R1
COND. HIGH
PRESS.
CUT-OUT
BEARING AND
MOTOR HIGH
TEMP CUT-OUT
REFRIG.
LOW TEMP.
CUT-OUT
G
G
G
G
G
R1
R5
TDR
CR
M3
2CR
R
VANE
CLOSED
R
G
CHILLED WATER
CUT-OUT &
RECYCLE SWITCH
P1
S
Y
LABY. GAS SOLENOID
S
REFRIG. AGITATOR SOLENOIDS
S
MOTOR LOAD CONTROL &
CHILLED WATER CONTROL
GUIDE
VANE
ACTUATOR
120 VOLTS
Y
OIL HEATER

Figure 91. Complete Control System Schematic

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ELECTRONIC CONTROL SYSTEM

In the previous discussion of centrifugal unit controls and unit wiring, mention was made of electronic controls. This unit will discuss the basic principle of operation of the Honeywell controls used on the 19D centrifugal machine.

The electronic control panel shown in figures 92 and 93 serves two different functions. It prevents motor overload by throttling the inlet guide vanes at preset conditions and controls machine capacity by regulating the position of the inlet guide vanes according to the temperature of the leaving chilled water.

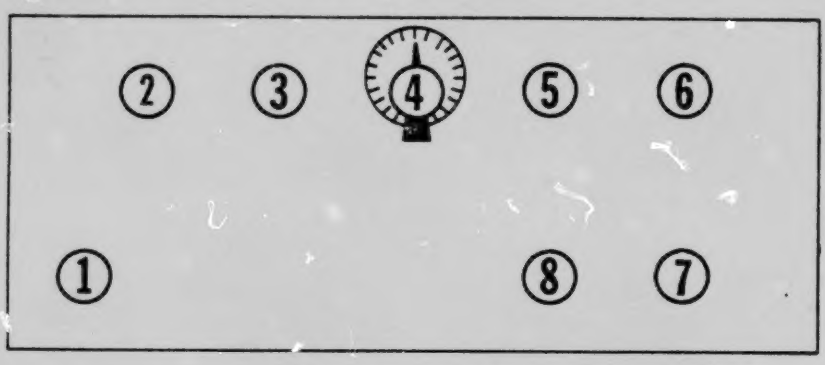


Figure 92

1. Electronic control ON-OFF switch
2. Machine START button
3. Vane DECREASE button
4. Chill water THERMOSTAT
5. Vane INCREASE button
6. Machine STOP button
7. Oil pump AUTO-MANUAL switch
8. Capacity control THERMOSTATIC-MANUAL switch

Under normal conditions the water leaving the cooler is controlled by the chilled water controller. A resistance element placed in the chilled water reacts to the temperature. The element is part of a bridge circuit from which signals are strengthened by an electronic amplifier, which in turn activates relays. The relays "open" or "close" to drive the electric vane motor, which "opens" or "closes" the compressor inlet guide vanes.

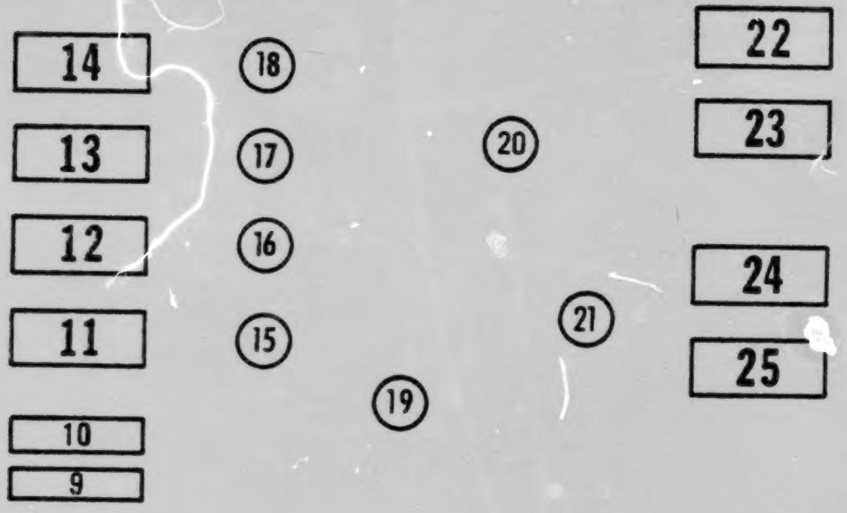


Figure 93

9. 3-Amp fuse - Safety control circuit
10. 3-Amp fuse - Refrigerant pump
11. Oil pump time delay relay
12. Relay R4
13. Relay R2
14. Relay R1
15. Differential adjusting screw
16. Capacity balance adjusting screw
17. Chilled water - Calibration adjusting screw
18. Motor load - Calibration adjusting screw
19. Throttling range adjusting screw
20. Electrical demand control knob
21. Test jack
22. Relay CR1
23. Relay CR2
24. Relay CRC
25. Relay CRO

Refer to figure 94. If the water temperature is within 1/2°F of the set point, relay contact CRC will be closed and CRO will be open. In this condition, neither the "open" or "close" winding of the capacitor start vane motor will be energized and the vane motor remains at a fixed position.

If the water temperature rises above the set point, relay CRO will pull in, energizing the "open" winding. The vane motor will drive the vanes "open" until a new balance position is reached. Relay CRO will then "open" deenergizing the "open" winding and the vanes stop.

A similar action takes place when the water temperature falls below the set point. Relay CRC will "open" causing contacts in R4 to close, thus energizing the "close" winding of the vane motor. The vane motor will drive toward "closed" until a new balance point is reached, opening relay CRC and the motor stops.

The vane motor is equipped with travel limit switches which prevent motor overtravel past full "open" or "closed." Relay R4 will cause the vanes to close on machine shutdown and they stay in that position until the machine is restarted.

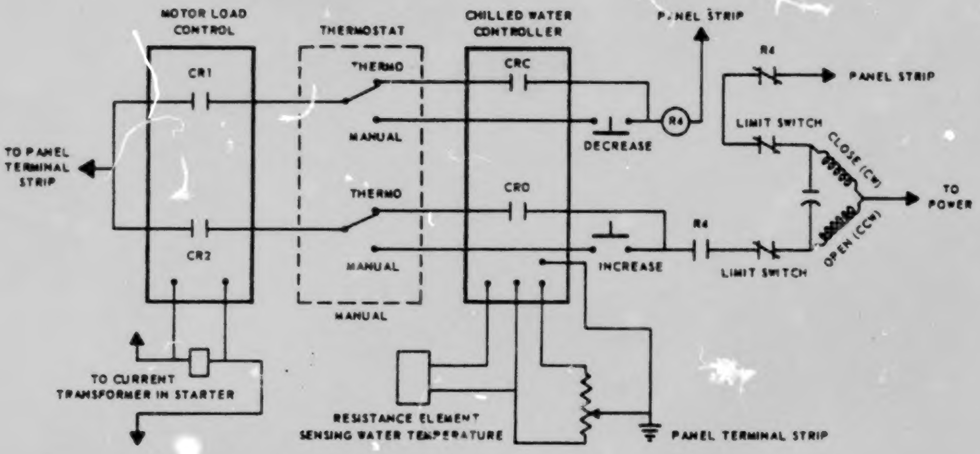

MOTOR LOAD CONTROL
THERMOSTAT
CHILLED WATER CONTROLLER
PANEL STRIP
CR1
THERMO
CRC
R4
PANEL STRIP
MANUAL
DECREASE
R4
LIMIT SWITCH
CLOSE (CW)
TO PANEL TERMINAL STRIP
THERMO
CRO
TO POWER
R4
CR2
MANUAL
INCREASE
LIMIT SWITCH
OPEN (CCW)
MANUAL
TO CURRENT TRANSFORMER IN STARTER
RESISTANCE ELEMENT SENSING WATER TEMPERATURE
PANEL TERMINAL STRIP

Figure 94

Motor overload is detected by a current transformer and resistor in the motor starter. An increase in current flow causes a voltage drop across the resistor. This change in voltage is amplified sufficiently to activate relays. The relays can interrupt the amplifier circuit independently of the chilled water relays, and can even prevent the vanes from opening further or cause them to close.

If the current flow reaches 103 percent of full load motor rating, relay CR2 will open and prevent the vanes from opening further. If the current draw continues to increase and reaches approximately 108 percent of full motor rating, relay CR1 will open and cause the vanes to "close" thus reducing the current draw. When this draw is reduced to approximately 106 percent, relay CR1 will close causing the vanes to stop moving. When the current flow drops to below 100 percent, relay CR2 will close and the machine is back under control of the chilled water control which will actuate the inlet guide vanes as described above.

The capacity control switch on the panel allows the operator to put the machine on "Thermostatic" or "Manual" control. When on manual, the leaving chilled water temperature is controlled by use of "higher" and "lower" pushbuttons. The inlet guide vanes will move only when one of these buttons is pushed, or if the motor overload control closes them. The motor overload control will override the manual signals at any time to prevent overloading the motor. When on "automatic" the chilled water temperature is automatically maintained.

An adjustable knob on the control known as the "electrical demand control" allows the operator to reduce the amount of current which can be drawn by the motor down to 40 percent of full load amperage.

The electronic ON-OFF control switch on the control panel provides current to the electronic control system. This switch is normally left in the ON position during the entire operating season to prevent the electronic system from being subjected to alternate cooling and heating stress.

A potentiometer with an adjusting knob is also on the panel. This is the "chilled water thermostat" and is electrically connected to the chilled water control. One division of the thermostat dial equals approximately 1°F. When calibrated, the pointer will be approximately at the center of the dial when set for designed chilled water temperature. This permits manual adjustment for colder or warmer water.

It must be understood that the above discussion has been very basic. Any adjustments to an operating machine should be made only after checking specific instructions by the equipment manufacturer.

SYSTEMS OPERATION

The centrifugal machine is stopped and started by the operating personnel. Definite operating instructions may be prepared by your installation supervisor, and are usually posted near the machine for ready reference.

It is very difficult to give definite instructions in this manual on the operation procedures for a given installation. Various design factors change the location of controls, types of controls used, and equipment location and will have a definite effect on operational procedures.

The procedures we will cover pertain to the 100-ton centrifugal unit located here at the school. These procedures are general in nature and should not be considered for use with field installed applications. When you encounter centrifugal units ALWAYS consult the specific manufacturers instructions.

Normal Starting Procedures

Listed below are the recommended steps that can be used in normal starting.

1. Check oil levels for motor, gear, couplings, compressor, and bearing wells.

2. Allow condenser water to circulate through the condenser, being sure to vent air and allow the water to flow through slowly. This precaution must be observed to avoid water hammer.

3. Allow chilled water to circulate through the cooler. Be sure to vent the air and allow the liquid to flow through slowly. As explained above, this will help in preventing water hammer.

4. Make sure that air pressure is present at all air-operated controls.

5. Start the purge unit before starting the machine; this helps in removing air from the machine. The purge recovery unit should be operated at all times while the machine is operating.

6. Make sure all safety controls have been reset and that the control lever is in OFF position.

7. Close the circuit breaker for all safety controls by pushing the start button in.

8. Bring the machine up to 75 percent of full load with all resistance in. Check oil gages to make sure proper oil pressure is being developed. If proper oil pressure is not developed in approximately 20 seconds, the machine will cut out on low oil pressure.

9. Open the valve to allow the cooling water to circulate to the compressor oil cooler, gear or turbine oil cooler and seal jacket. The water circulating to the compressor oil cooler must be kept low enough in temperature to prevent the highest bearing temperature from exceeding a temperature of 180°F. The seal bearing temperature should run approximately 160°F, while the thrust bearing temperature runs at approximately 145°F under normal operating conditions. These temperatures should be checked closely until they maintain a satisfactory point.

10. After starting, the machine may surge until the air in the condenser has been removed. During this surging period, the machine should be run at high speed; this helps the process of purging. The condenser pressure should not exceed 12 psig and the input current to motor-driven machines should not run over 100 percent of the full load motor rating. The machine will steady itself out as all the air has been purged. After leveling out the motor speed, the damper may be adjusted to give the desired coolant temperature. The motor should be increased slowly, point to point. Do not proceed to the next speed point until the motor has obtained a steady speed. Keep a close observation on the ammeter to make sure that the motor does not become overloaded.

Normal and Emergency Shutdown

NOTE: Normal and emergency shutdown procedures are performed in the same manner.

The following steps are used in shutting down the centrifugal machine.

1. Stop the motor by throwing the switch on the controller.

2. After the machine has stopped, turn off the water valve which supplies water to the compressor oil, gear oil cooler, and the seal housing.

3. Shut down all pumps as required.

Shutdown periods may be broken down into two classes, standby and extended shutdown. Standby shutdown may be defined as the period of time during which the machine must be available for immediate use, while extended shutdown is defined as that period of time during which the machine is out of service.

STANDBY SHUTDOWN. The following checks must be made during standby shutdown and corrective action taken.

1. Maintain proper oil lever in the oil reservoir and in the suction damper stuffing box.

2. Room temperature must be above freezing.

3. Machine must be kept free of leaks.

4. Purge unit must be operated as necessary to keep the machine pressure below atmospheric pressure.

5. If the machine pressure builds up in the unit due to room temperature rather than leakage of air into the machine, a small quantity of water circulated through the condenser or cooler will hold the machine pressure below atmospheric. Periodic operation of the purge unit will accomplish the same result.

6. The machine should be operated a few minutes each week to circulate oil and lower the refrigerant temperature.

EXTENDED SHUTDOWN. If the system is free of leaks and the purge unit holds down the machine pressure, the following instructions and corrective actions must be taken in long shutdown periods.

1. Drain all water from the compressor, gear and turbine oil cooler, condenser, cooler, seal jacket, pumps, and piping if freezing temperatures are likely to develop in the machine room.

2. It is possible for the oil to become excessively diluted with refrigerant causing the oil level in the pump chamber to rise. This level should not be allowed to rise into the gear bearing chamber; if this occurs, remove the entire charge of oil.

LOGS AND RECORDS

A daily operating log is maintained at each attended plant for a record of observed temperature readings, waterflow, maintenance performed, and any unusual condition occurring which affects an installation operation. The operator is held responsible for keeping an accurate log while on duty.

A master chart of maintenance duties, each component identified, is usually prepared by the installation supervisor and includes daily, weekly, and monthly maintenance services. The maintenance items included on the chart are applicable to a specific installation. The items on the chart must be checked accordingly.

The master chart is placed near the operating equipment for ready reference so that operators can identify the specific maintenance service required.

The supervisor schedules operator maintenance duties which are selected from the master chart. Each operator, while on duty, must perform the outlined job and enter his progress in the daily log.

A good log will help the operator locate troubles rapidly. A typical log sheet has spaces for all important entries and a carefully kept log will help make troubleshooting easier.

SYSTEMS MAINTENANCE

It is very difficult to set up a definite maintenance schedule since so many operational factors must be considered. Your supervisor should familiarize you with the standing operating procedures at your installation and you must follow these recommendations.

The tubes in the condenser and cooler must receive regular attention for efficient performance and long life. Special care must be taken during the first year of operation due to dirt and other foreign materials which may have collected in the system during installation. The water treating system must operate effectively to prevent general corrosion of the tubes and piping system. Foreign material and corrosive attack can do extensive damage to the system's piping and water tubes if not effectively treated and corrected.

A special type of nylon brush should be used to clean tubes. This brush is designed to prevent scraping or scratching of the tube's inner wall. The brush is forced through each tube by hand pressure. During this cleaning process most of the scale, mud, and other foreign deposits will be loosened. The removal of such loose deposits can be accomplished by flushing with water.

If the tubes are completely covered with scale, a chemical treating process must be used to remove all foreign deposits. The manufacturer's maintenance manual will give information on the type and strength of chemical solution to use on their designed units.

Condenser

It is recommended that the condenser tubes be brushed at least once a year. Hourly checks must be made between the difference of the leaving condenser water temperature and the condensing temperature. If at full load operation, this difference exceeds the design value, fouling of tube surfaces is taking place. Should the leaving chilled water temperature be hard to maintain, cleaning of the condenser tubes is recommended.

SERVICING. The following procedures should be followed in cleaning condenser tubes.

1. Shut off the main line inlet and outlet valves.

2. Drain water from condenser through the water box drain valve. Open the vent cock in the gage line or remove the gage to help draining.

3. Remove all nuts from the water box covers, leaving two on loosely for safety.

4. Using specially threaded jacking bolts, force the covers away from the flanges. As soon as the covers are loose from the gaskets, secure a rope to the rigging bolt in the covers and an overhead support. Remove the last two nuts and place the cover on the floor.

5. Scrape both the cover and the matching flange to free any gasket material.

6. Remove the water box division plate by sliding it out from its grooves. Caution should be used in removing this plate; it is made of cast iron. Penetrating oil may be used to help remove the plate.

7. Use a nylon brush or equal type on the end of a long rod. Clean each tube with a scrubbing motion and flush each tube after the brushing has been completed.

CAUTION: Do not permit tubes to be exposed to air long enough to dry before cleaning as dry sludge is more difficult to remove.

8. Replace the division plate after first shellacking the required round rubber gasket in the two grooves.

9. Replace the water box covers after first putting graphite on both sides of each gasket as this prevents sticking of the gaskets to the flanges.

CAUTION: Care must be taken with the water box cover on the water box end to see that the division plate matches the rib of the flanges.

10. Tighten all nuts evenly.

11. Close the drain and gage cock.

12. Open the main line water valve and fill the tubes with water. Operate the pump, if possible, to check for leak-tight joints.

REPAIR. Retubing is about the only major repair that is done on the condenser. This takes a high degree of skill and may require the services of a manufacturer's qualified repairman.

Evaporator or Cooler

You will be required to make frequent checks of the chilled water temperatures in the evaporator. If these temperature readings at full-load operation begin to vary from the designed temperatures, fouling of the tube surfaces is beginning and cleaning is required when leaving chilled water temperature cannot be maintained.

In cleaning the evaporator, it is recommended that the tubes be cleaned at least once a year, which may vary with local operating conditions. Cleaning schedules should be outlined in the standard operating procedures.

SERVICING. Servicing procedures for shell-and-tube type evaporators and condensers are the same since all shell-and-tube containers are built and operate on similar principles.

REPAIR. Retubing is about the only major repair that is done on the evaporator. This work should be done by a qualified refrigeration repairman or a manufacturer's representative.

Charging the Unit

The manufacturer usually ships the refrigerant in large metal drums. These drums weigh approximately 200 pounds. At temperature above 74.8°F, the drum will be under pressure. To prevent loss of refrigerant or injury, never open the drums to atmosphere when above this temperature. It is possible to charge refrigerant from an open drum at 60°F temperature, although it is recommended that leak-tight connections be made to the charging valve. The charging valve is located on the side of the cooler. To help in the charging procedure, each refrigerant drum has a special type of plug installed on the side of the drum. This plug is specifically engineered for charging purposes. The charging connection on the drum consists of a two-inch plug in which is inserted a smaller 3/4-inch plug. The 3/4-inch opening inside the drum is covered with a friction cap. The cap prevents leakage into or out of the drum when the 3/4-inch plug is unscrewed. To charge the machine with refrigerant, proceed as follows:

1. The machine must be under a vacuum.

2. Install a 3/4-inch nipple into the standard globe valve and close the valve.

3. Remove the 3/4-inch plug inserted in the two-inch plug from the drum.

4. Place the valve with the nipple into the opening, making sure that it is far enough in to push off the cap inside the drum.

5. Place the drum in a horizontal position near the cooler charging valve with the use of a hoist. The drum should be high enough to allow the refrigerant to flow as a liquid, by gravity, from the drum to the charging line. Rotate the drum so that the valve is at the bottom.

6. Connect the two valves (drum and cooler) with a copper tube and fittings, making sure all the joints are leakproof.

7. Open both valves and allow the refrigerant to flow into the cooler. Operate the machine to maintain a vacuum after the initial reduction to zero.

8. When the drum is empty, close the valve on the cooler and disconnect the drum. Remove the valve for use with the next drum. Complete charging of the machine requires 600 pounds of R-11.

ADDING REFRIGERANT TO MAINTAIN A STANDARD LEVEL. When adding refrigerant, use the same procedures as explained above. Another method that can be used to add refrigerant is to simply allow the refrigerant to be drawn in as a gas. This can be done by letting the drum rest on the floor and letting the gas escape into the cooler while the machine is in operation or idle.

Removing Refrigerant Charge

In removing refrigerant from the cooler, the following procedure is recommended.

1. Inject air into the machine until a pressure of two to five pounds gage is reached by use of the purge recovery unit.

2. Connect tubing to the charging valve on the cooler and allow the refrigerant to discharge into the refrigerant drum.

3. Less loss of refrigerant will take place if the refrigerant is cold. Always allow space in the drum for refrigerant expansion.

Oil Replacement

1. Gage pressure in the machine should run approximately 1 psig.
2. Drain oil from the bottom of the main oil reservoir cover.
3. Remove the main oil reservoir cover and clean the chamber to remove all impurities.
4. Replace the main oil reservoir cover.
5. Remove access bearing cover plate.
6. Lift up the shaft bearing caps by reaching through the bearing access hole and removing the two large capscrews.
7. Fill the bearing approximately 3/4 of the full charge, allowing the excess oil to flow into the main oil reservoir.
8. Replace the bearing cap and secure with capscrews.
9. Remove the brass plug from the thrust housing and remove the strainer; clean and replace.
10. Replace the plug and secure.
11. Drain oil through the plug in back of the seal oil reservoir.
12. Remove the cover from the seal oil reservoir.
13. Refill the reservoir with new oil.
14. Replace the cover and secure.
15. Drain the oil through the plug at the bottom of the oil reservoir that is vented to the atmosphere.
16. Remove plug in the atmospheric oil reservoir and pour in fresh oil until the level is halfway in the atmospheric float chamber sight glass.
17. Replace the plug and secure.
18. Operate the purge unit to remove as much air as possible before starting the machine.
19. Add oil to the atmospheric float chamber, if main oil reservoir indicates an undercharge after a short period of operation.

MAINTENANCE CHECKLIST

The following checklist should be used in inspecting the many components of the centrifugal machine. Maintenance problems will be greatly reduced by using the following schedule. This schedule is outlined in AFM 85-18.

		Inspection Interval									
	COMPRESSOR	Hourly	Daily	Weekly	Monthly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
	COMPRESSOR										
1.	Review operating log				x						
2.	Complete oil change							x		x	
3.	Check oil filter pressure drop		x								
4.	Renew seal oil filter					x			x		2
5.	Clean thrust oil strainer							x		x	
6.	Check oil pump drive							x		x	
7.	Check oil heater and flow switch			x					x	x	
8.	Oil level in pump chamber	x							x	x	
9.	Oil level atmospheric chamber	x							x	x	
10.	Oil level seal oil reservoir		x							x	
11.	Oil pressure seal chamber	x							x		
12.	Oil pressure back of seal	x							x		
13.	Shaft bearing temperatures	x							x		
14.	Inspect seal									x	1
15.	Shaft bearing clearances							x		x	
16.	Shaft labyrinth clearances									x	1
17.	Thrust bearing							x		x	
18.	Oil cooler - water leak										1

	Hourly	Daily	Weekly	Montly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
19. Oil safety cutout - in				x				x		
20 High pressure safety cutout				x				x		
21. Water to seal water jacket	x							x		
22. Water to oil cooler	x							x		
23. Seal opening clearance							x		x	

NOTE:
1. Perform inspections and tests as found necessary.
2. As often as required.
3. Add oil when idle.

COOLER

	Hourly	Daily	Weekly	Montly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
1. Review operating logs				x						
2. Refrigerant level - machine idle				x					x	
3. Refrigerant temperature - machine running	x							x		
4. Check for fouled tubes							x	x	x	1
5. Refrigerant contamination									x	1
6. Low temperature refrigerant cutout				x				x		
7. Low water temperature cutout				x				x		
8. Condition of insulation										1
9. Leak test - low side						x			x	1
10. Seal on suction damper		x						x	x	
11. Rupture valve						x			x	

	Inspection Interval									
	Hourly	Daily	Weekly	Monthly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
CONDENSER										
1. Review operating logs				x						
2. Check for fouled tubes							x	x	x	1
3. Leak test high side				x				x		
4. Check for air and noncondensable gases		x						x		
PURGE RECOVERY UNIT										
1. Compressor oil change						x			x	
2. Oil level	x							x		
3. Refrigerant level in separation chamber		x						x		
4. Pressurestat cutout						x		x		
5. Relief valve setting				x				x		
6. Regulating valve operation		x						x		
7. Suction - discharge pressure	x							x		
8. Water Collection		x						x		
9. Excessive purging	x							x		
10. Motor lubrication - cleanliness				x					x	
11. Belts-condition-alignment					x			x		
12. Compressor efficiency				x			x			
13. Clean condenser				x					x	

	Inspection Interval									
	Hourly	Daily	Weekly	Monthly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
14. Oil separator float					x			x		
15. Pressure test			x				x	x		
NOTE: 1. Perform inspections and tests as found necessary. 2. As often as required. 3. Add oil when idle.										
GEAR										
1. Oil level		x						x		
2. Oil pressure	x							x		
3. Clean oil strainer					x				x	1
4. Condition of teeth and bearings							x		x	1
5. Operating temperature	x							x		
6. Water to oil cooler	x							x		
7. Change oil							x		x	1
COUPLINGS										
1. Check lubrication			x						x	
2. Clean - renew lubricant						x			x	
3. Check alignment and wear							x		x	

	Inspection Interval									
	Hourly	Daily	Weekly	Monthly	Quarterly	Twice Yearly	Yearly	Running	Stopped	Remarks
MOTOR - CONTROLLER										
1. Bearing oil level		x						x	x	3
2. Collector rings and brushes						x			x	
3. Bearing condition									x	1
4. Bearing oil change						x			x	1
5. Condition of contacts					x				x	

NOTE:
1. Perform inspections and tests as found necessary.
2. As often as required.
3. Add oil when idle.

TROUBLE DIAGNOSIS CHART

The steps to be taken in detecting and correcting operation of the centrifugal machine are outlined in the following trouble diagnosis chart. Use the proper methods for making these service adjustments, repairs, and corrections as outlined in this chapter.

All settings, clearances, and adjustments must be made to the manufacturer's specifications. The manufacturer's maintenance catalog gives definite clearances, temperatures, pressures, and positions for adjustment of component parts. These tolerances must be set as recommended for efficient operation. Carelessness in these settings can cause extensive damage to the machine.

TROUBLE	PROBABLE CAUSE	REMEDY
High head pressure	Low on condenser water	Check condenser water pump for proper operation.
	Sealed and dirty condenser tubes	Inspect and clean condenser tubes.
	Division plate rupture	Remove air from lines.
	Air in condenser. (Check differences between leaving water temperature and condensing temperature)	Operate purge unit; find and repair leak.
	Condenser float valve in economizer stuck closed	Adjust float, examine valve seat, and eliminate cause of sticking.
	Condenser not transferring enough heat	Check items listed in (high condenser pressure).
Loss of capacity	Hot gas bypass valve open	Close valve.
	Gradual contamination of refrigerant by oil	Replace refrigerant charge.
	Sudden increase in difference between refrigerant and water temperature	Check division plates and gaskets in cooler water box for breakage.
	Gradual increase in water and refrigerant temperature	Clean cooler tubes; remove excess oil from refrigerant, check division plates and gaskets.
Compressor surges	Load too light	Open hot gas bypass.
	Air leak	Run purge unit and repair leak
	High condenser pressure	Check items listed in "high head pressure."
Refrigerant (R-11)too low	Charge lost or trapped in condenser or economizer by sticking floats	Find leak, check floats, add refrigerant after determining cause of leak.
	Purge unit leaking	Check relief valve.

TROUBLE	PROBABLE CAUSE	REMEDY
Compressor second stage frosts	Economizer float valve stuck	Check float operation.
	Light load with cold condenser	Decrease flow of condenser water.
	Suction damper closure causes circulation of condensate from economizer	Readjust suction damper controls to give a greater opening of damper.
Low-back of seal pressure with high seal pressure	Dirty filter	Remove, inspect and clean filter.
	Filter cartridge improperly installed	Check installation of filter and replace correctly.
Compressor bearing too high	Insufficient flow of cooling water throughout oil cooler	Open throttling cock to oil cooler.
	Excessive dilution of oil by the refrigerant upon startup or electric oil heater off during shutdown	Operate electric oil heater during shutdown.
	Temperature in pump chamber above 150°F when compressor is started	Turn on cooling water sooner on starting, check for clogged cooling coil. Check and clean.
	Thrust or shaft bearing scored	Check bearing and shaft end clearance.
Gear overheated	High oil level	Drain excess oil.
	Dirty oil level	Drain excess oil.
	Dirty cooler	Clean cooler tubes.
	Low cooling waterflow	Increase cooling waterflow

SUMMARY

Direct expansion refrigeration systems pump refrigerant directly through the cooling coil, whereas indirect systems pump chill water or brine through the cooling coil. Indirect refrigeration may be either of the centrifugal or reciprocating type.

There are several companies that manufacture the centrifugal machine. Except for a few engineering differences, these machines are the same. When in doubt about any maintenance or operational procedure, refer to the manufacturer's manuals or handbooks for specific information.

An itemized checklist and operational log must be used and maintained by the operator on duty. Careful inspections will help in correcting malfunctions and give the machine long life and efficient operation.

REFERENCES:

Textbook; Modern Refrigeration and Air Conditioning, Althouse, Turnquist, Bracciano

Textbook; Basic Refrigeration, King

Textbook; Principles of Refrigeration, Dossat

Manual; Carrier Centrifugal Refrigeration Equipment 190

ABSORPTION SYSTEMS

OBJECTIVES:

This study guide will aid you in learning the major components of a lithium-bromide absorption system. It will also aid you in learning all the fluid lines, pumps, and fluid flow through the system. Capacity control of the unit will also be discussed.

INTRODUCTION

An absorption machine has very little electrical power requirement for the great cooling ability that it has. The power to operate the cycle comes from a heat source such as steam or hot water. The job of the absorption cycle is the same as that of a centrifugal machine. It must cool a secondary refrigerant which in turn will cool the actual air in the room or the air being delivered to the room.

ABSORPTION SYSTEMS

A given air-conditioning system can use any one of several refrigeration plants. Reciprocating and centrifugal plants were discussed in detail in previous lessons. In this unit of study you will learn the operation of absorption systems used for air conditioning.

The use of the aqua-lithium bromide absorption system began in 1945. The principle of operation was a century old but, until this time, it had never been completely safe, successful or economical. These systems are used for air conditioning, and their capacities range from three to over 1000 tons. The absorption unit is in great demand at the present time in large installations. The machine's low operating cost, dependability, minimum maintenance and space requirement, long life, and serviceability are its major advantages.

Absorption Unit Construction

The majority of absorption machines consists of two cylindrical shells (upper and lower). The upper shell contains the generator and condenser assemblies, while the lower shell contains the evaporator and absorber assemblies. Other minor units such as the unit heat exchanger, unit pumps and electrical components are located between the supporting legs of the unit.

System Fluids

The absorption air-conditioning unit is of the water-chiller type. It is a forced circulation machine using steam or hot water as the energy source or activating medium Water is used as the refrigerant and Lithium Bromide salt as the absorbant. Lithium bromide is called the "thirsty" salt. It is similar in appearance to table salt and is capable of absorbing a high percentage of water vapor. Therefore, the working fluids in the absorption system are water and lithium bromide. These fluids are inexpensive, plentiful, nontoxic, nonexplosive and create no health or fire hazards. Neither fluid deteriorates within the system and once charged it should not be necessary to replace either one.

BASIC ABSORPTION CYCLE

Successful operation of an absorption machine is based on two principles called the "keys" to operation. They are:

1. The ability of lithium bromide to absorb a large amount of water vapor.

2. The ability to make water boil or flash cool itself at low temperatures by subjecting it to a high (deep) vacuum.

For water to boil in the evaporator at 38°F a vacuum of approximately 29.65 inches mercury is required. To illustrate the necessity of maintaining this vacuum, an increase of only 0.06 psi in the unit will raise the leaving chilled water temperature 10°F.

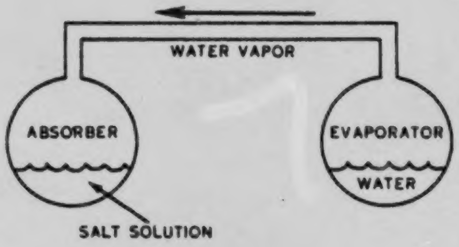


Figure 95. Absorption Schematic, Part A

To understand the operation of the refrigeration cycle, think of two self-contained vessels, one containing the salt solution (which is known as the absorber) and the other containing water (known as the evaporator). Join the two containers as they are in figure 95. Ordinary table salt absorbs water vapor when it is exposed to damp weather. The salt solution in the absorber has a much greater ability to absorb the water vapor from the evaporator. The water that remains in the evaporator is chilled by evaporation, which produces a refrigeration or cooling effect within the tank. Both the absorber and evaporator are in a vacuum. This vacuum causes water to boil at a much lower temperature. Because of this, the chilled water can be cooled down to a temperature of 38°F. The evaporator has a pump (shown in figure 96) which moves the cooled water from the evaporator tank to the spray header. This header sprays the cooled water over the surface of a set of chilled water coils. The evaporation and cooling effect of this spray on the surface of the chilled water coils cools the water inside the coils as it recirculates through the system.

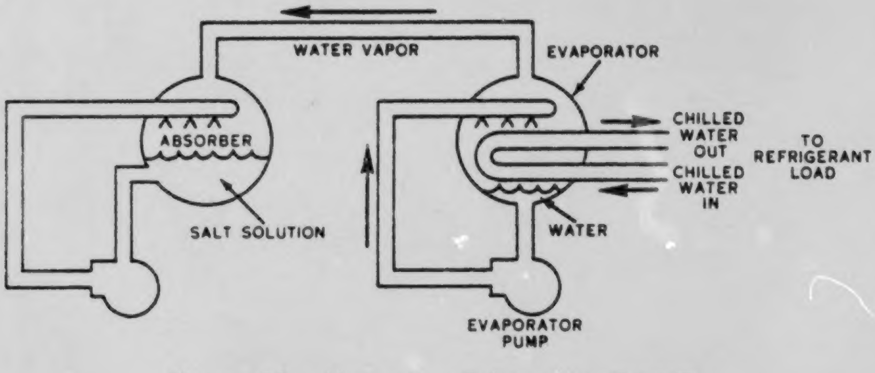


Figure 96. Absorption Schematic, Part B

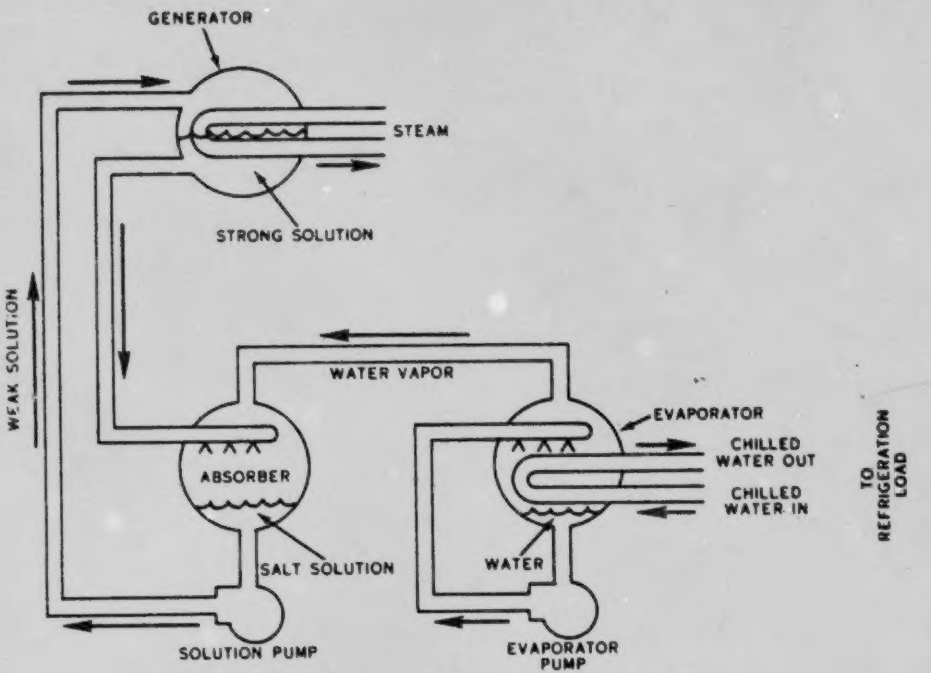

GENERATOR
STEAM
STRONG SOLUTION
WEAK SOLUTION
WATER VAPOR
EVAPORATOR
CHILLED WATER OUT
CHILLED WATER IN
TO REFRIGERATION LOAD
ABSORBER
SALT SOLUTION
WATER
SOLUTION PUMP
EVAPORATOR PUMP

Figure 97. Absorption Schematic, Part C

When the water drips from the coils, it will fall into the evaporator tank. Some of the spray will be absorbed by the lithium bromide that is also being sprayed in the absorber (figure 97). After the salt solution has absorbed as much as it can, the solution becomes weak. It will not absorb any more water vapor. This weak solution is pumped through the heat exchanger to the generator, figure 98, where steam coils cause the water to boil off and leave a strong salt solution. The strong solution will drain from the generator back to the absorber. The water vapor will rise to the condenser. The condensing waterline from the cooling tower will cool the vapors enough for them to liquefy. This water flows back to the evaporator tank where it is pumped through the spray header across the coils. The vapor that did not condense in the condenser will flow to the purge unit, and the noncondensable air is discharged into the atmosphere.

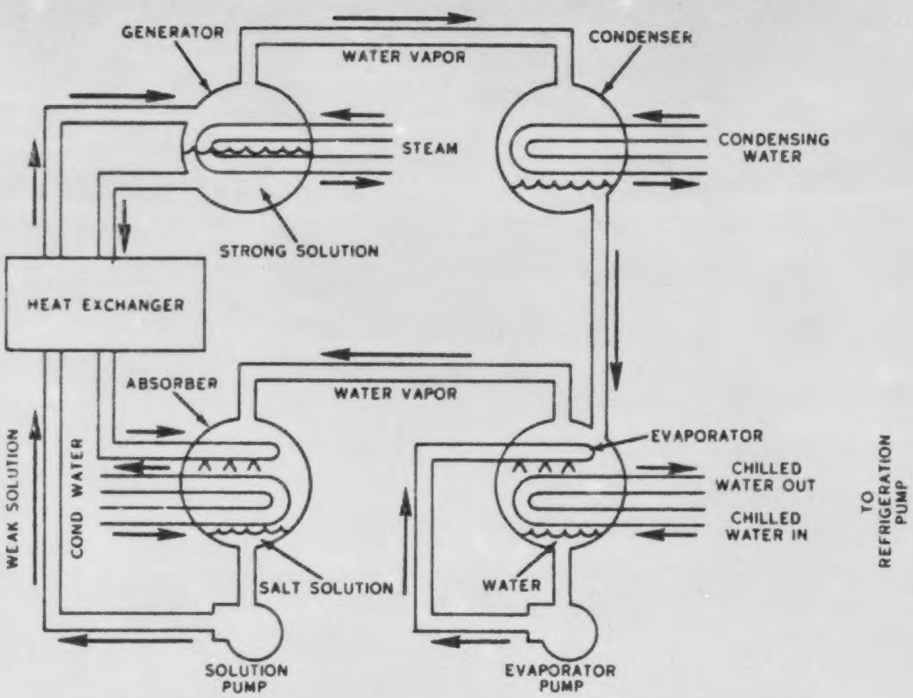

GENERATOR
WATER VAPOR
CONDENSER
STEAM
CONDENSING WATER
STRONG SOLUTION
HEAT EXCHANGER
ABSORBER
WATER VAPOR
EVAPORATOR
CHILLED WATER OUT
CHILLED WATER IN
TO REFRIGERATION PUMP
WEAK SOLUTION
COND WATER
SALT SOLUTION
WATER
SOLUTION PUMP
EVAPORATOR PUMP

Figure 98. Absorption Schematic, Part D

We can compare the basic absorption cycle with the mechanical compression cycle which you have already learned. Refer to figure 99 as you proceed for the comparison.

To simplify the absorption cycle we will start the cycle at the outlet of the condenser and not at the compressor as you are accustomed to.

High pressure liquid refrigerant (water) passes from the condenser (1) through an orifice or restrictor (2) and expands into the lower pressure evaporator (3). As the refrigerant (water) is discharged from the orifice into the evaporator (3) the refrigerant (water) is cooled by flash evaporation. The heat will flow from the water circulating through the conditioned space to the liquid refrigerant, vaporizing the refrigerant.

The refrigerant, now a vapor, flows to the absorber (4) where the pressure is the lowest in the system. In the absorber the vapor is absorbed by the lithium bromide, a salt solution. A combination of absorbent and refrigerant, now mixed, forms a diluted or weak solution. This diluted solution being heavier than the strong absorbent settles to the bottom of the absorber shell where it is pulled out by the solution pump (5). The weak solution is now pumped to the generator or concentrator (6). The refrigerant is recovered from the absorbent in this component by distillation. Heat is applied to the solution by means of low pressure steam or hot water boiling out the refrigerant. The strong absorbent solution returns to the absorber and repeats the process. The refrigerant vapor passes to the condenser (1) where it is cooled and condensed by cooling tower water flowing through a tube bundle.

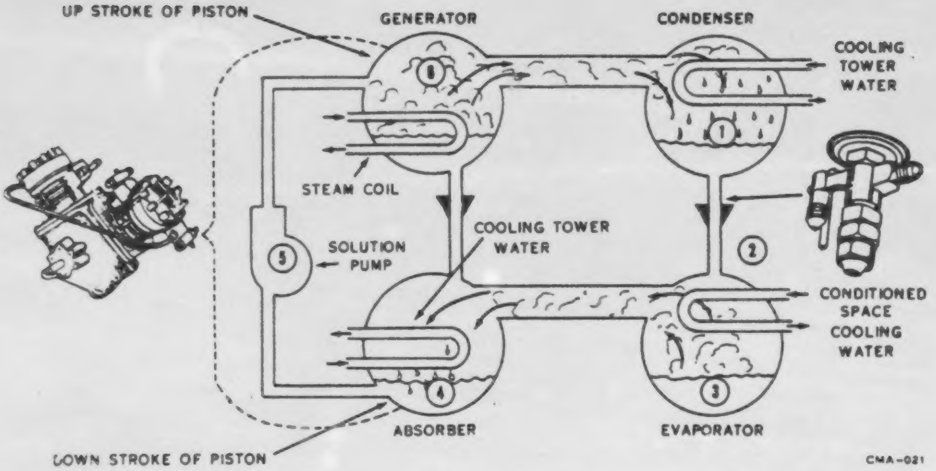


Figure 99. Compression-Absorption Comparison

EVAPORATOR. Chilled water flows through the evaporator tube bundle. It is cooled by the refrigerant being sprayed over the tubes. The chilled water is then pumped to where it furnishes cooling. A refrigerant collection pan, located below the chilled water coils, collects, and stores the refrigerant for further cycling.

ABSORBER. The water vapor formed in the evaporator is absorbed by the lithium-bromide solution that is being circulated in the absorber. Cooling water from the tower flows through the tube bundle in the absorber removing the heat of absorption, heat of condensation and sensible heat. The lithium bromide must be kept cool to absorb water.

GENERATOR. Lithium-bromide solution is pumped from the absorber to the generator where low-pressure steam, or hot water, provides the heat necessary to boil the solution. Boiling removes the water that was absorbed in the absorber and makes a strong solution out of the weak solution. The strong solution then returns to the absorber section. The low-pressure steam or hot water comes from a boiler.

CONDENSER. The water vapor produced in the generator is condensed in the condenser by the relatively cool condenser water flowing from the absorber. A water pan collects the condensed water vapor and returns it to the evaporator section.

HEAT EXCHANGER. A shell and tube heat exchanger in the lines between the absorber and generator transfers heat from the hot strong solution that is leaving the generator to the weak solution that is entering the generator. This increases the machine's efficiency by causing the solution to be in the generator for a shorter period of time.

PURGE UNIT. The purge unit is a necessary part of the machine. It removes, stores, and discharges to the atmosphere, all air and noncondensables accumulated in the machine.

Figure 100 shows the configuration of the machine more realistically.

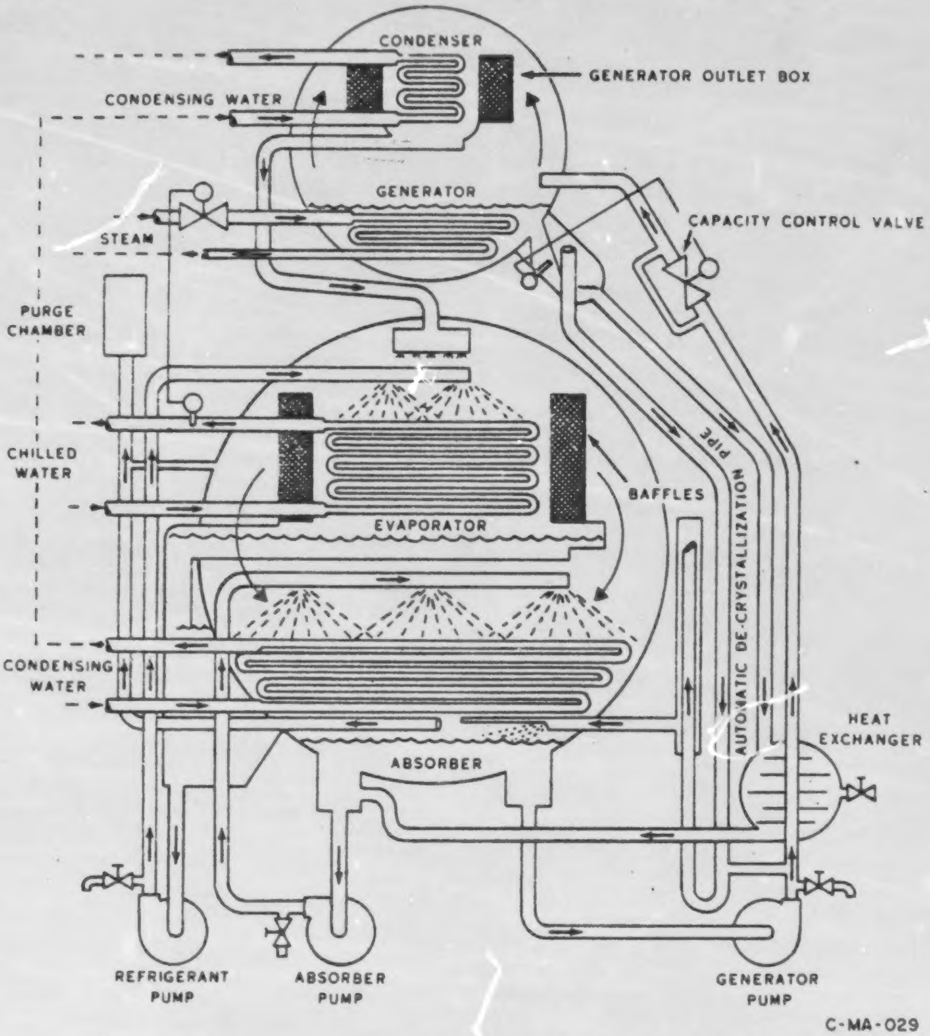

CONDENSER
GENERATOR OUTLET BOX
CONDENSING WATER
GENERATOR
STEAM
CAPACITY CONTROL VALVE
PURGE CHAMBER
CHILLED WATER
BAFFLES
AUTOMATIC DE-CRYSTALLIZATION PIPE
EVAPORATOR
CONDENSING WATER
HEAT EXCHANGER
ABSORBER
REFRIGERANT PUMP
ABSORBER PUMP
GENERATOR PUMP
C-MA-029

Figure 100. Absorption Refrigeration Machine

PUMPS. The pumps that are used with an absorption air conditioner are usually of the centrifugal type. They are equipped with mechanical seals when they are used in a vacuum, as they are on an absorption air conditioner. These seals require a head of water for lubrication so that water rather than air enters the unit in case the seal leaks. On the later model units the pump and pump motor are hermetically sealed.

SOLUTION CONCENTRATION AND DILUTION

During operation the solution concentration in the machine changes constantly depending on the capacity being produced. At full load capacity the concentration is high, as the load decreases the concentration is lower. When the solution is at high concentration and allowed to cool, it will solidify or crystallize. This will cause no permanent damage to the machine. The machine simply cannot produce cooling because the solution cannot be circulated.

Solidification can be caused by the following:

1. Air leak
2. Operation with condenser water below design temperature
3. Power failure of sufficient length to allow the machine to cool down
4. Improper solution and refrigerant charges
5. Shutting the machine down with insufficient dilution time

During operation the solution is concentrated, therefore it must be diluted before the machine is shut down. This is accomplished automatically. When the stop button is pushed the steam capacity control valve closes, the rest of the machine will continue to operate for approximately seven minutes. During this time the solution in the absorber is absorbing water vapor, but since the capacity control valve is closed and the solution cannot be concentrated, it will be diluted. This process will be covered in a later unit.

CHECKS AND SERVICE OF ABSORPTION MACHINES

Loss of Vacuum

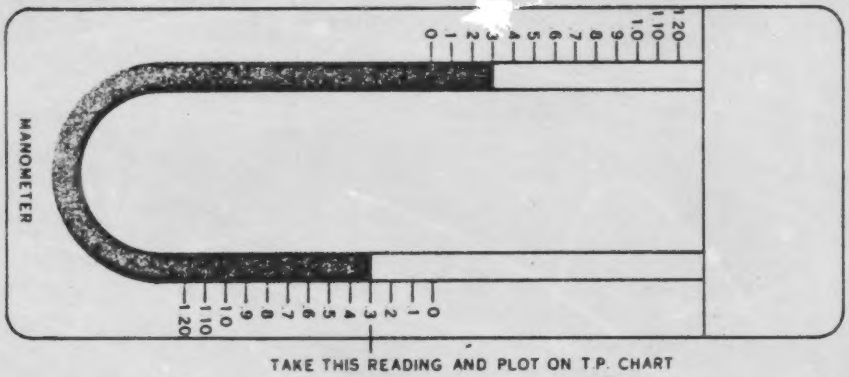
This problem may occur as the results of an air leak, loss of purge, bad pump seal, etc. When air leaks into the system, the absorber pressure rises with the presence of noncondensables, thus limiting evaporator capacity. The leaving chilled water temperature will then rise, which signals the steam valve to open. This causes the generator temperature to increase and produces a more concentrated solution. With the increasing pressure there is less load on the absorber which results in a decrease in the diluted solution temperature. This cooler diluted solution, passing through the heat exchanger, cools the concentrated solution sufficiently to cause crystallization. Air leakage, without a doubt, is the worst enemy of absorption equipment. The consequences are serious because in the presence of air, lithium-bromide becomes corrosive to metal and is subject to solidification.

CHECKING MACHINE VACUUM, STANDING VACUUM TEST. Before starting the absorption machine, you must check to see if air has leaked into the machine. This is accomplished as follows:

1. Determine the absolute pressure in the machine by reading and logging the manometer located on the machine.

2. Wait 24 hours.

3. Again read the manometer. If the pressure reading in the machine is more than .1 inch mercury above the previous reading, there is air in the machine and a leak test must be performed.


MANOMETER
0
1
2
3
4
5
6
7
8
9
10
110
120
TAKE THIS READING AND PLOT ON T.P. CHART

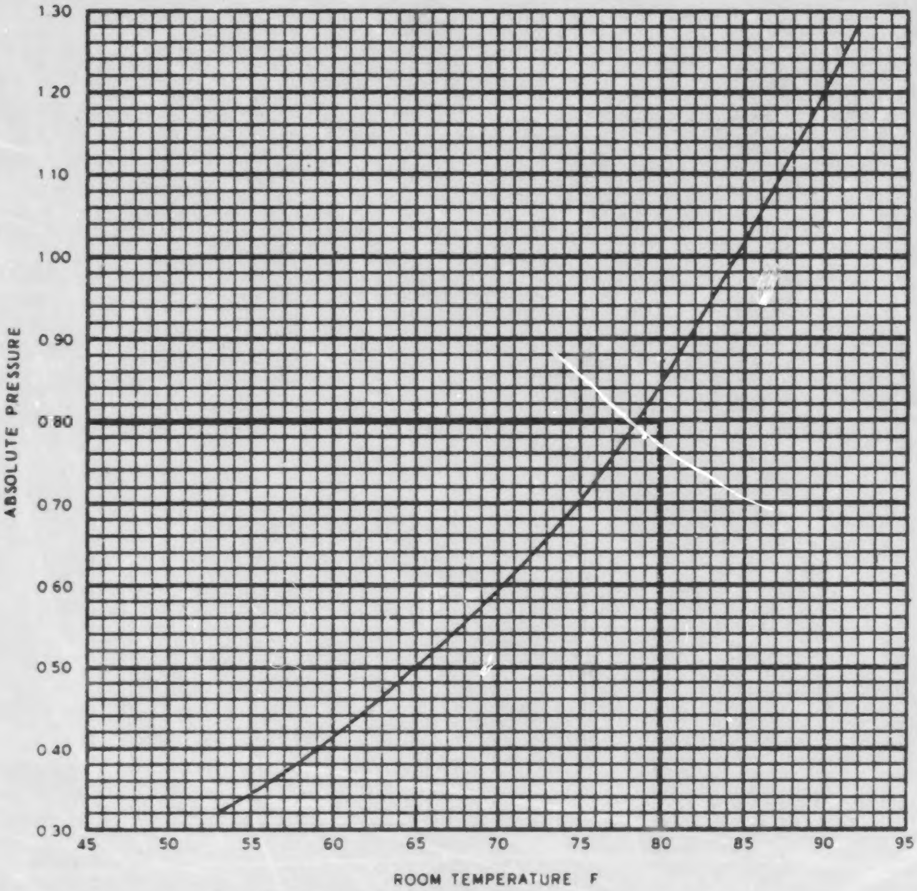


Figure 101. Temperature-Pressure Chart

RUNNING VACUUM TEST. This test is performed on an operating machine. To accomplish this test proceed as follows:

1. Take the manometer reading (figure 101) and the ambient temperature of the machine room.

2. With these two known values, plot the pressure-temperature curve as shown in figure 101.

NOTE: For example, with a machine room temperature of 80°F and a manometer reading of 0.80 absolute pressure, the point of intersection of the lines is below the curve.

3. If the plotted temperature and pressure is .1 inch mercury above the curve there is air in the machine and a leak check must be performed.

LEAK DETECTION TEST. If the standing or running vacuum tests indicate a leak in the machine it can be located by the following procedure:

1. Break the machine vacuum by charging the machine to a pressure of 5 psig using Refrigerant 12.

2. Continue charging with nitrogen to a pressure of 18 psig.

3. When this charging operation is complete, test the system carefully with a leak detector preferably of the electronic type.

4. If service work is to be performed and the machine opened to atmosphere, the pressure regulator on the nitrogen cylinder should be set to constantly bleed 1 psig into the machine.

Charging with Refrigerant and Solution

After all maintenance is completed and the system passes a satisfactory vacuum test, the unit is ready to be charged with solution and refrigerant. To charge with refrigerant, connect a vacuum pump to the purge connection and let it run for several minutes to lower the absolute pressure of the system. See figure 102.

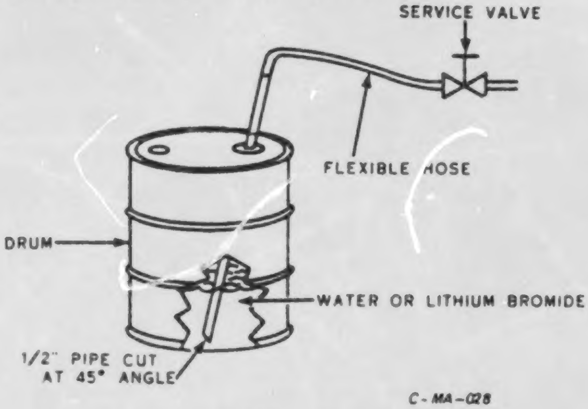


Figure 102. Charging Setup

Solution Charging:

1. Connect flexible hose to 1/2" pipe. Cut end of pipe at a 45° angle to prevent pipe from sealing itself on bottom of drum. Fill both pipe and hose with water.

2. Insert pipe into drum and connect flexible hose to solution pump service valve.

3. Open service valve. Charge the system with the amount specified by the manufacturer for the particular unit. Caution should be exercised to never let the liquid level in the drum drop below the end on the pipe. If this should happen air would be drawn into the unit.

Refrigerant Charging:

1. Same procedure as solution charging.

2. Insert pipe into drum and connect flexible hose to refrigerant pump service valve.

3. Same procedure as solution charging.

Level and Concentration Checks

SOLUTION LEVEL. The solution level in the absorber must be checked. Normal operating level is approximately one-third of the absorber sight glass at full load operation. At partial-load operation, the solution level will vary between one-third and two-thirds of the sight glass.

REFRIGERANT LEVEL. The refrigerant level is visually checked through the sight glass located on the evaporator. At a high level the water may spill over the evaporator tank into the solution in the absorber, causing a loss of operating efficiency. A low level will cause the evaporator water pump to surge (cavitate) when it is running. A low refrigerant level results in less refrigeration effect.

ADD OCTYL ALCOHOL. With the machine running, add the recommended amount of octyl alcohol to the solution through the alcohol charging valve in the absorber pump discharge line. The discharge pressure of the absorber solution pump is approximately five to fifteen inches of vacuum; therefore, even with the pump running, it will be possible to draw the alcohol into the machine. This cleans the outside of the tubes in the generator and absorber and improves their efficiency in transferring heat.

REMOVING REFRIGERANT OR SOLUTION. When it is necessary to remove a part or all of the system charge, you may use one of the two methods below. On some units the pump discharge pressure is above atmospheric. On these units just open a valve on the pump discharge and drain out the quantity desired. On units that all pressures are below atmospheric, remove the charge using the following procedure. Refer to figure 103 (1) Connect vacuum hoses to service valve, flask, and vacuum pump. (2) Operate vacuum pump to bring flask pressure below absorption unit pressure. (3) Open service valve and solution or refrigerant will flow into flask.

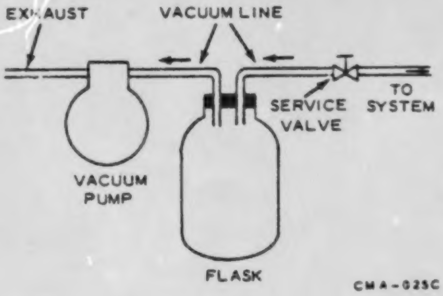


Figure 103. Removing Refrigerant or Solution

505

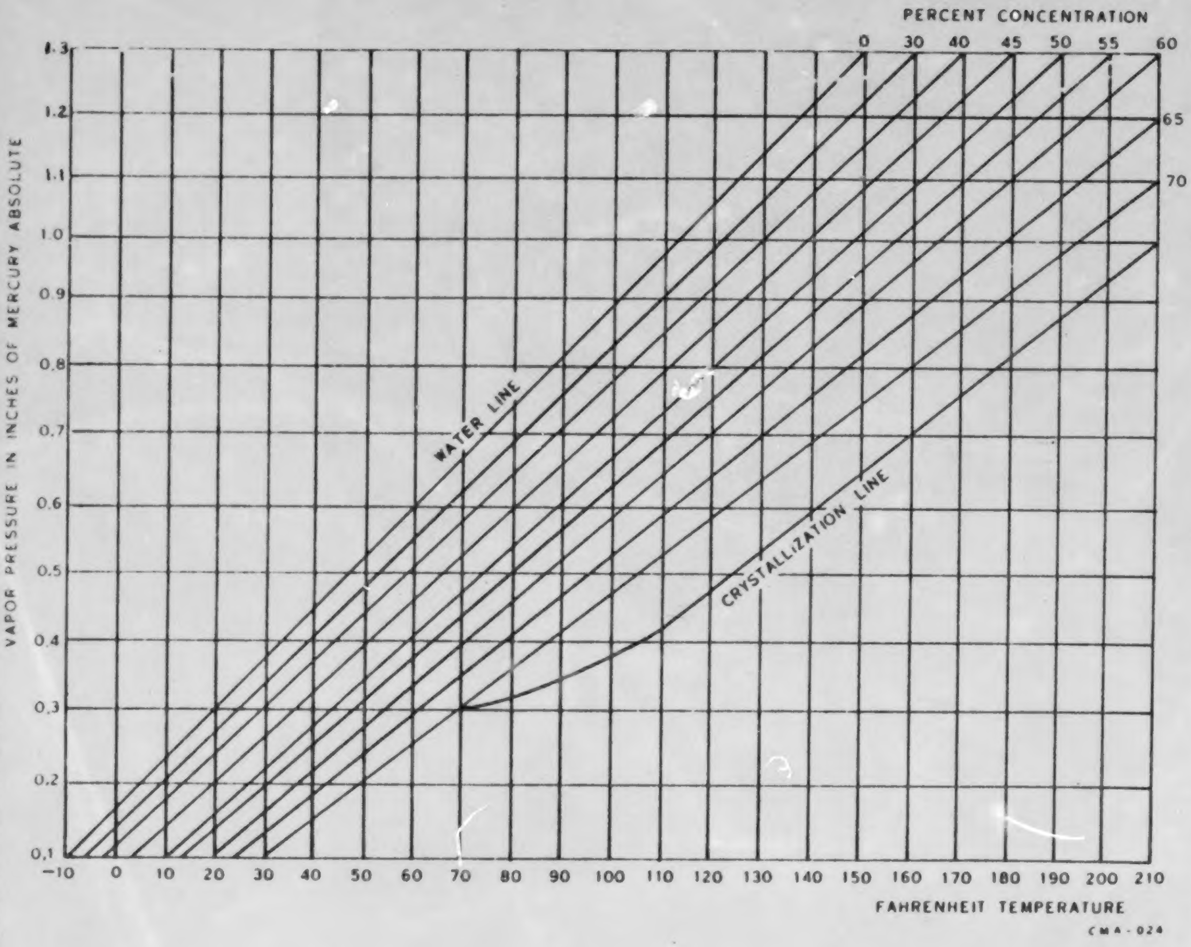


Figure 104. Operation Check Diagram

SOLUTION CONCENTRATION CHECK. A common characteristic of the lithium bromide absorption air conditioner is that the lithium-bromide solution will crystallize or solidify under certain conditions. To solidify or crystallize means the absorbent changes from a liquid to a solid state. Solidification will cause the unit to stop, but will not cause permanent damage to the unit. After the solution is desolidified, the unit may be placed back in operation. To desolidify you would dilute the solidified area with system liquids and, if necessary, apply heat. One method used to determine solution concentration (percent of lithium-bromide to water) is as follows. We will use some figures to form an example along with the diagram in figure 104. Use 100° for the temperature of the refrigerant leaving the condenser. Follow the 100° line upward until it gets to the diagonal waterline, mark the chart at this point. Use 160° for the temperature of the solution leaving the generator. Using the mark that you have already made on the chart, go horizontally to the right until you intersect the 160° vertical line. At this point read the solution concentration from the diagonal lines, it would be 65 percent.

During operation the solution concentration should not exceed the 65 percent figure. From the above example, it is obvious the generator is operating at its maximum concentration. If this concentration is allowed to increase, slush will form in the heat exchanger and prevent the concentrated solution from flowing.

With the steam valve fully open and the solution concentration check indicates the concentration is over 65 percent, the following steps should be taken immediately.

1. Throttle the steam to the generator until the solution checks indicate the concentration is at a safe level of 64 to 65 percent.

2. Check the refrigerant level in the evaporator sight glass. If a low level is indicated it may be necessary to add refrigerant to the system.

TYPICAL ABSORPTION UNIT CONTROLS

Operation

The operation of an absorption air conditioner can be compared to an expensive airplane. When either one is out of control, they do not perform the way they should. It is, therefore, important that you understand the control circuits of the lithium-bromide system.

Absorption systems use electric, electronic, and pneumatic controls. We will explain the operation of a typical control circuit as you refer to figure 105.

When the main switch is turned on, it supplies voltage to the control voltage line. The start-stop switch (S/S) is energized to the start position, starting the chilled water pump through LS-2 which is interlocked with a set of auxiliary motor starter contacts. In series with the auxiliary contacts is a flow switch (FS). Once flow has been established in the chilled water circuit, the flow switch (FS) closes supplying voltage to the pneumatic electric switch (PE).

Upon a rise in temperature in the chilled water supply line, the branch line pressure of the chilled water thermostat (T-1) will rise. The rise in branch line pressure causes the contacts in the pneumatic electric switch (PE) to close, which energize the condensing water line starter (LS-3) starting the condenser pump. The cooling tower line starter (LS-4) is energized simultaneously through auxiliary contacts starting the cooling tower fan. Once the cooling tower fan is in operation the cooling tower thermostat (T-2) will cycle the fan on and off to maintain designed cooling water temperature.

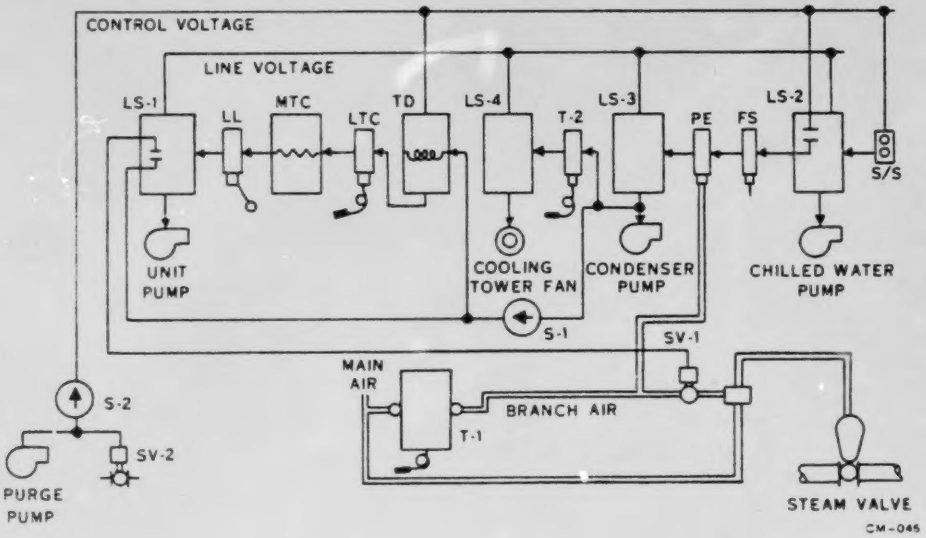


Figure 105. Lithium-Bromide Electrical System

Turning the system's on-off switch (S-1) on, energizing the time delay relay (TD). This supplies control voltage to the unit pump's line starter (LS-1) through the normally closed low temperature control (LTC), motor temperature control (MTC), and the liquid level switch (LL) starting the pumps.

Energizing the unit pump line starter (LS-1) closes auxiliary contacts to supply control voltage to the solenoid air valve (SV-1). This opens the solenoid supplying branch pressure to the steam valve.

Systems water temperature changes are sensed by the chilled water thermostat (T-1). The thermostat responds by varying the branch line pressure to the steam valve.

When lower chilled water temperature is sensed by T-1, indicating that cooling is no longer needed, the branch line pressure will decrease causing the pneumatic electric switch (PE) to open. This deenergizes the condenser pump line starter (LS-3) which in turn deenergizes the time delay relay (TD), solenoid air valve (SV-1), and the cooling tower fan line starter (LS-4) stopping the fan. The loss of control voltage to the solenoid air valve (SV-1) causes the steam valve to close, stopping steam to the generator.

Prior to complete shutdown, the unit pumps will continue to operate for approximately seven minutes, under control of the time delay relay (TD), allowing the mixture of weak and strong solution. This equalization of the solution throughout the solution handling portion of the system eliminates the possibility of crystallization during shutdown.

The purge pump and purge pump solenoid valve (SV-2) are energized by closing the purge pump on and off switch (S-2)

ADJUSTMENT OF ABSORPTION UNIT CAPACITY CONTROL SYSTEM

The operation of the machine can only be as good as the units which control it. You must understand that various manufacturers use different controls, each selected to meet specific needs of the installation. You should of course, consult the manufacturer's manuals before attempting to calibrate any control. The general information we shall discuss covers the Honeywell LP 914A sensor and RP 908A controller.

LP 914A Sensor

CONSTRUCTION. The LP 914A sensor is inserted into a well at the chilled water line and is connected with conventional pneumatic tubing to the RP 908A controller. Figure 106 shows the sensor. Figure 107 shows the internal construction of the sensor.

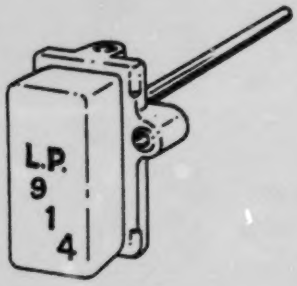


Figure 106. LP 914 Sensor

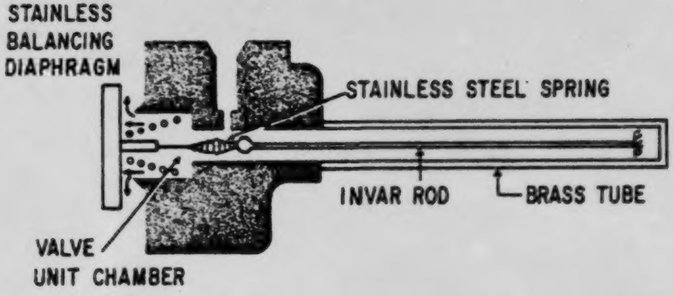


Figure 107. LP 914 Internal Construction

This temperature sensor, which we shall discuss and work with has an Invar rod, brass tube, and a stainless steel balancing diaphragm as its working parts.

The sensor will operate accurately at a distance of one mile or less and is not affected by vibration. Total movement of the stainless steel balancing diaphragm is less than one ten-thousands (.0001) of an inch.

The sensor is designed to always have a minimum of 3 psig applied and a maximum of 15 psig applied. It has a sensitivity of .06 psi/1°F temperature change. LP 914A sensors are available in various temperature ranges. The sensor we will discuss has a range of -40 to + 160°F.

CALIBRATION. The sensor is factory calibrated and sealed with a plastic cover. If the sensor fails, the complete sensor must be replaced. DO NOT ATTEMPT TO CALIBRATE.

OPERATION. On an increase in temperature, the brass rod expands, moving the invar rod away from the steel balancing chamber pulling it closed. With the diaphragm closed the pressure will back up into the input chamber of the RP 908A to a possible maximum of 15 psig.

On a decrease in temperature, the brass rod will contract, causing the invar rod to move the steel diaphram away from the seat. This will allow all pressure above 3 psig to escape to atmosphere.

It was stated earlier that the LP 914A sensor was factory calibrated, however, there are two methods for checking the operation of the sensor.

Refer to figure 108 which illustrates a pneumatic temperature-pressure chart. The temperature AT THE SENSOR is measured and plotted vertically from the bottom of the chart to the diagonal line. A horizontal line is plotted from this point to the psi range. A gage installed in the sensor line should correspond to this reading. For example, a sensor temperature of 70°F should equal 9.6 psig.

Alternate Method Without Chart:

The measured temperature at the sensor is 70°F.

The lowest range (base) of this sensor is -40°F.

The sensitivity of the sensor is 0.6 psi/1°F.

The sensor will always have 3 psig applied.

Mathematically,	start with the measured temperature	70°F.
	add the base range of the sensor	+40°F.
		110
	Multiply the sensitivity	x.06
		6.6
	add the 3 psig always applied	3
	the sensor line pressure gage should read	9.6 psig

If the gage line pressure does not equal the psig required, check all air lines for leaks before condemning the sensor.

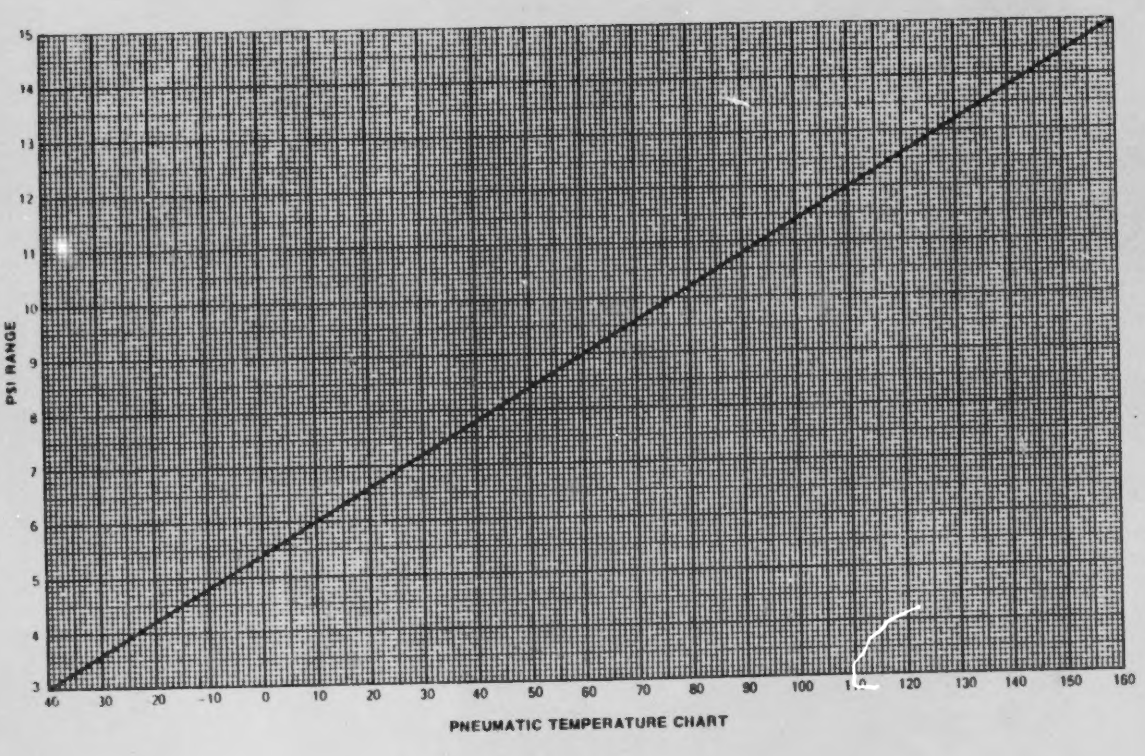


Figure 108. Pneumatic Temperature Chart

RP 906A Controller

CONSTRUCTION. The RP 908A controller consists primarily of a three-pipe manifold labeled "B" for outgoing branch line to the controlled device (steam valve), "M" for incoming main or supply air and "1" for sensor input to and from the LP 914A, an L shaped lever, and valve unit with relay chamber. Refer to figure 109.

OPERATION. The main air enters the controller where it passes through a small restrictor to port "1", which is connected to the sensor and the input chamber. On a rise in chilled water temperature, pressure in both the sensor line and the input chamber move the main lever against the set point adjustment spring.

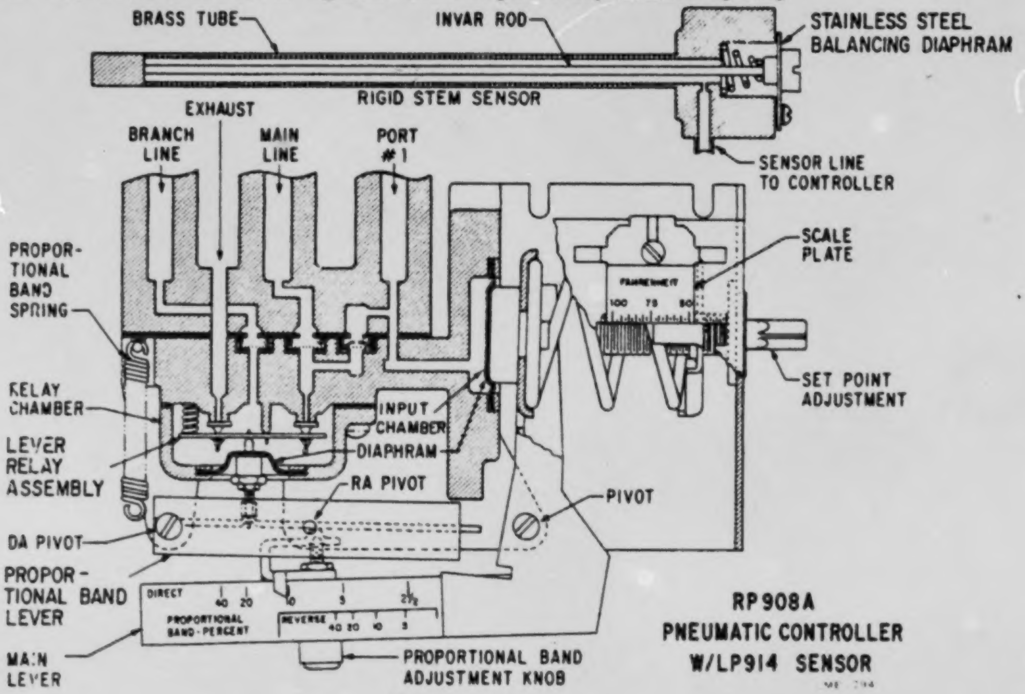

BRASS TUBE
INVAR ROD
STAINLESS STEEL BALANCING DIAPHRAM
RIGID STEM SENSOR
B
SENSOR LINE TO CONTROLLER
EXHAUST
BRANCH LINE
MAIN LINE
PORT #1
SCALE PLATE
PROPORTIONAL BAND SPRING
SET POINT ADJUSTMENT
RELAY CHAMBER
INPUT CHAMBER
DIAPHRAM
LEVER RELAY ASSEMBLY
RA PIVOT
PIVOT
DA PIVOT
PROPORTIONAL BAND LEVER
DIRECT
40 20 10 5 2½
PROPORTIONAL BAND-PERCENT
REVERSE 40 20 10 5
MAIN LEVER
PROPORTIONAL BAND ADJUSTMENT KNOB
RP908A
PNEUMATIC CONTROLLER
W/LP914 SENSOR

Figure 109

This movement causes the relay lever assembly to pivot the exhaust port closed, which causes the main airport to open allowing the air pressure to enter the relay chamber, thus supply air to the branch line and operating the controlled device (steam valve).

On a decrease in chilled water temperature the sensor will bleed the pressure from the input chamber, causing all levers to move in the opposite direction. The relay lever will pivot closing the main air port allowing the branch line pressure to bleed out the exhaust port. This is termed DIRECT ACTING OPERATION.

To transform the RP 908A into a reverse-acting device it is necessary to move the proportional band lever pivot screws to the reverse acting position. By doing so, the proportional band lever, relay operating arm and relay lever move in the opposite direction. The branch line and input chamber pressure FALL on a RISE in temperature.

NOTE:

1. All controllers are set for direct action control as received from the vendor.

2. Doublecheck all controllers against the below sketches before installing into the control panel.

3. When setting up a controller for reverse action, remove the controller from the mounting plate by removing the three mounting screws. Connect springs and move pivot screws as indicated in figure 110 which can be found inside the controller cover.

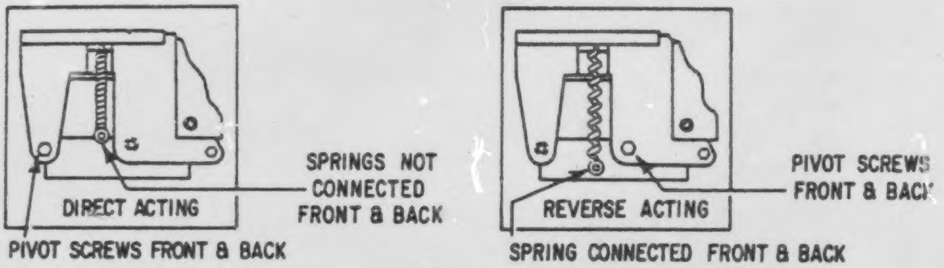

SPRINGS NOT CONNECTED FRONT & BACK
DIRECT ACTING
PIVOT SCREWS FRONT & BACK
PIVOT SCREWS FRONT & BACK
REVERSE ACTING
SPRING CONNECTED FRONT & BACK

Figure 110. Changing Action of Controller

CALIBRATING THE RP 908A CHILLED WATER CONTROLLER.

PROCEDURE:

1. Check that the springs and pivot screws on the controller are set to provide direct action required by this controller.

2. The branch line connecting the controller with the sensor must be tight and free of leaks.

3. Proportional band adjustment; proportional band is the change in variable (temperature) required to move the controlled device (steam valve) from one of its extreme limits of travel to the other and is expressed in percent of the controller scale plate, it is adjustable from 2 1/2 percent to 40 percent on the RP 908A.

The controller has a spring which must be connected to the main lever when the proportional band setting is 15 percent and above. See figure 111.

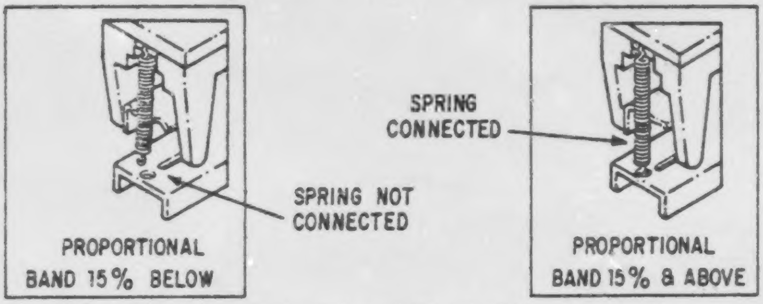

SPRING CONNECTED
SPRING NOT CONNECTED
PROPORTIONAL BAND 15% BELOW
PROPORTIONAL BAND 15% & ABOVE

Figure 111. Changing Proportional Band of the Controller

The RP 908A comes from the manufacturer with an assortment of scale ranges that will coincide with the range of the LP 914A sensor or any portion of that range, making the controller an extremely versatile instrument. The range we will use, for example, is 50°F to 100°F.

The proportional band adjustment or setting can be made before the system is placed into operation. Adjustment is as follows:

a. Loosen the proportional band adjustment knob and move the knob sideways until the pointer indicates the desired proportional band setting. For our discussion we will use a setting of 10 on the direct-acting scale. This setting of 10 will give a 5 percent range of the 50° F to 100°F scale plate. Compute as follows:

Scale Range	50°F to 100°F
Total Range	100-50°F or 50°F
P. B. Setting	10 percent

$$\begin{array}{r} 50 \\ \times\ .10 \\ \hline 5.00 \end{array}$$ or 5 percent usable range

With this figure determined we can now set the controller to maintain our desired condition.

4. Measure the temperature at the sensor.

5. Turn the set point adjustment knob to Midspring Range of the steam valve.

   The amount of pressure required to move the valve from closed to open is the spring range of the valve. The spring range of a given valve can be determined by applying pressure to see when the valve starts to move and when it has moved as far as it will go. If the valve starts moving at 7 psig and completes its move at 11 psig the spring range is 7 to 11 psig.

   This means the valve will not move until 7 psig is applied and will be fully open at 11 psig.

   The midspring range can be determined by adding the high and low and dividing by 2. For example 11 + 7 = 18 and 18 ÷ 2 is 9. When the controller sends 9 psig to the valve it will be half open or in the midposition.

6. Move the scale plate slider to indicate the temperature measured at the sensor.

7. Turn the set point knob to the desired temperature.

8. The controller is now calibrated.

517

WORKBOOKS 3AZR54550-2-III-1-P1 thru III-4-P5

Department of Civil Engineering Training

Refrigeration and Air Conditioning Equipment

AIR CONDITIONING AND CALCULATIONS

October 1974

AIR TRAINING COMMAND

SHEPPARD AIR FORCE BASE

11-9

Designed For ATC Course Use

DO NOT USE ON THE JOB

REFRIGERATION AND AIR CONDITIONING EQUIPMENT

PROJECT		PAGE
III-1-P1	Determining Wet Bulb, Dry Bulb and Wet Bulb Depression	1
III-1-P2	Air Conditioning Process Calculations	3
III-2-P1	Operate and Service Window Air Conditioning	19
III-2-P2	Operate and Electrically Troubleshoot Residential Air Conditioning	25
III-3-P1	Centrifugal Refrigeration Components and Cycle	33
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This supersedes SG 3AZR54550-2-III-1 thru 4, 3AZR54550-2-III-P1 thru 4-P2,
3 January 1973

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-1-P1
2 October 1974

DETERMINING WET BULB, DRY BULB, AND WET BULB DEPRESSION

OBJECTIVES

Upon completion of this project you will be able to:

Determine dry bulb temperature, wet bulb temperature, and compute the wet bulb depression.

Standard of performance

The standard of performance of this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-1-P1	1/student
Sling Psychrometer	1/12 students
Chart, Psychrometric	1/student
Ductulator	1/student
Pen or pencil	1/student

Using sling psychrometer to determine wet and dry bulb temperatures under varying conditions following instructions below.

1. Using a sling psychrometer, wet the wet bulb thermometer and rotate the psychrometer rapidly until the reading on the wet bulb thermometer reaches the lowest point and stabilizes (about 30 seconds).

2. On the following chart, record the reading from both the wet bulb and dry bulb thermometers. Determine the wet bulb depression of the problem.

DRY BULB TEMPERATURE	WET BULB TEMPERATURE	WET BULB DEPRESSION

Determine the wet bulb depression of the problem.

DRY BULB TEMPERATURE	WET BULB TEMPERATURE	WET BULB DEPRESSION
85°F	75°F	
80°F	74°F	
78°F	72°F	
92°F	85°F	
75°F	68°F	

3. Answer the following questions:

   a. Why does the thermometer with the wet wick indicate a lower temperature than the dry thermometer?

   ____

   ____

   b. When using the sling psychrometer, the difference between the reading of the wet and dry bulb thermometer is called

   ____

   ____

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-1-P2

AIR CONDITIONING PROCESS CALCULATIONS

OBJECTIVES

Upon completion of this project you will be able to:

1. Plot given or measured air conditions on a psychrometric chart to determine the other properties of the air.
2. Use reference tables and a load estimate form to determine the sensible, latent, total hourly heat load, and the sensible heat ratio of the heat load.
3. Determine the final condition of airs being mixed together in different proportions and of different original conditions.
4. Determine the supply air condition and volume required to remove the hourly sensible and latent heat loads in order to maintain room conditions.
5. Use air flow balancing instrument to balance the air flow volume to the rooms of the building.
6. Adjust the air volumes to meet the specifications.

Standard of performance

The standard of performance of this project is 100 percent completion, errorfree

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-1-P2	1/student
Chart, Psychrometric	1/student
Sling Psychrometer	1/12 students
Ductulator	1/student
Pen or Pencil	1/student

PROCEDURE:

PART I

TERMINOLOGY

Using the list of terms and definitions listed below, place the letter of corresponding definition on the line provided after the term.

1. Dry Bulb Temperature ____________
2. Wet Bulb Temperature ____________
3. Relative Humidity ________________
4. Dewpoint Temperature (Saturation) ____________________
5. Grains of Moisture (Specific Humidity ______________
6. Heat Content ____________________
7. Standard Air ____________________

A. The ratio of the amount of moisture in the air compared to what it could hold at the same temperature.

B. The ambient air temperature and is read on an ordinary thermometer.

C. The temperature at which moisture condenses from the air.

D. The temperature at which air ceases to be cooled by evaporation.

E. The amount of heat in the air, measured in Btus.

F. One pound of dry air at 70 degrees F., which occupies 13.34 cubic feet and has a specific density of .075 at atmospheric pressure of 14.7 psia or 0 gage, at sea level.

G. The amount of moisture in the air measured in grains.

PART II

PLOTTING AIR PROPERTIES

1. Supply all missing values, using the Psychrometric Chart furnished by the instructor.

	DB	WB	RH	DP	Gr/lb	HC
1	72F				59gr	
2		61F	45%			
3	85F		60%			
4	68F			24F		
5		71F			39 gr	

2. Under saturated conditions, how much more vapor can 60°F air hold than 30°F air?

____

3. A room air conditioner was started when the temperature was 75°F and the relative humidity (RH) was 70 percent:

   a. How much moisture did the air contain? ______________________

   b. After three hours of operation, the temperature was 70°F and RH was 50 percent.

   c. How much moisture had been removed? ______________________

4. A homeowner complains of dryness from his hot air heating system. When checked, the DB temperature was 72°F and the WB temperature was 48°F.

   a. What is the relative humidity (RH)? ______________________

   b. How much moisture must be added to the system to bring the RH up to 50 percent? ______________________

Have the instructor check your work.

PART III

HEAT LOAD ESTIMATING

INSTRUCTIONS

Use the information from the following survey and the building diagram to estimate the heat load on the following load estimate form.

		DB	WB	GM
LOCATION _______ LAT. _________	DESIGN CONDITIONS			
DATE __________ BLDG ORIENTATION _______	OUTSIDE			
BUILDING DEMENSIONS: 46' X 25'X 12' (L, W, H)	INSIDE			
BUILDING USAGE: Normally occupied by 20 students and instructors.	DIFF.		XXXX	

HEAT LOAD SOURCE		Sensible	Latent	Subtotal
SOLAR HEAT GAIN	SQ FT X FACTOR =	BTUS		
N. glass	_____ X _____	_____		
E. glass	_____ X _____	_____		
S. glass	_____ X _____	_____		
W. glass	_____ X _____	_____		
			*****	_____
WALL HEAT GAIN	SQ FT X FACT X TD =	BTUS		
N. wall	_____ X _____ X _____	_____		
E. wall	_____ X _____ X _____	_____		
S. wall	_____ X _____ X _____	_____		
W. wall	_____ X _____ X _____	_____		
Floor	_____ X _____ X _____	_____		
Ceiling	_____ X _____ X _____	_____		
Roof	_____ X _____ X _____	_____	*****	_____

VENTILATION AND/OR INFILTRATION

1. Sensible: ____ x ____ x 1.08
cfm td

2. Latent: ____ x ____ x .68
cfm gr. moi. diff.

INTERIOR

1. Personnel no. people x Btu = BTUS

____ x ____ ____

____ x ____

2. Equipment

Lights ____ x 3.4
watts

Motors ____ x 3393
horsepower

Appliances (see table) *actual values ind.

____

____

____

SENSIBLE HEAT GAIN TOTAL

LATENT HEAT GAIN TOTAL

TOTAL BTU HEAT GAIN

TONNAGE REQUIREMENT $\frac{\text{BTUH}}{\text{12,000 BTUH}}$

COMMENTS:

LOAD ESTIMATE SURVEY

BUILDING LOCATION: DALLAS, TEXAS

BUILDING ORIENTATION: SOUTH

BUILDING CONSTRUCTION:

FLOOR - SLAB (CONCRETE)

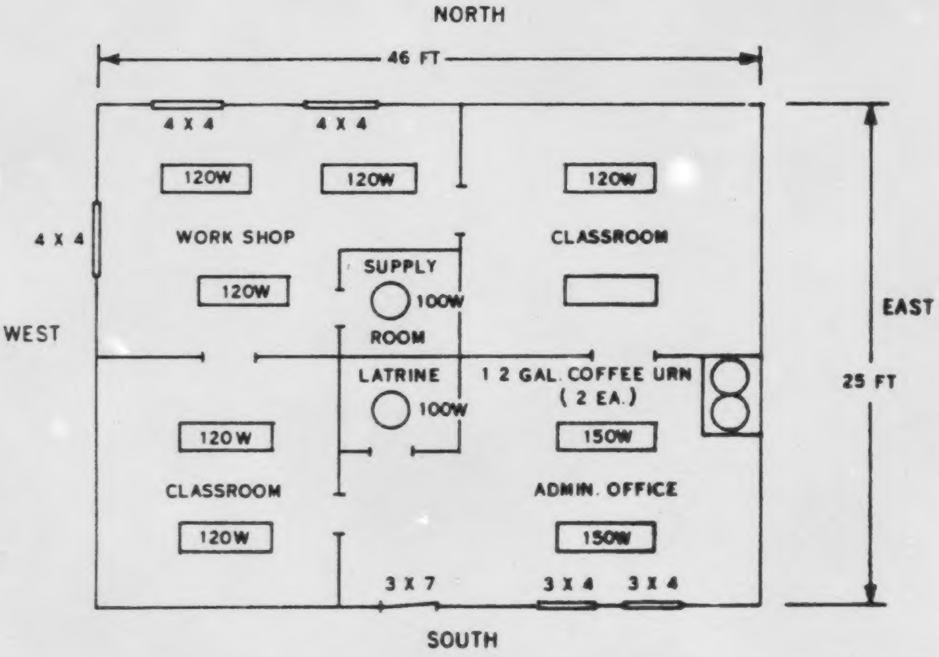
WALLS - COMMON BRICK (MASONRY) 8 in. thick plus 1 in. insulating board on the inside walls.

ROOF - FLAT, 3 in. WOOD DECK, built-up roofing and 1 in. insulation on top of the deck; 3 in. fiberous insulation inside deck.

CEILING - CEILING AND ROOF ARE THE SAME

DIMENTIONS AND DETAILS:

# SHOWN ON ATTACHED BUILDING DRAWING.


NORTH
46 FT
4 X 4
4 X 4
120W
120W
120W
4 X 4
WORK SHOP
CLASSROOM
SUPPLY
120W
100W
ROOM
WEST
EAST
LATRINE
1 2 GAL. COFFEE URN
(2 EA.)
25 FT
100W
120W
150W
CLASSROOM
ADMIN. OFFICE
120W
150W
3 X 7
3 X 4
3 X 4
SOUTH

PART IV

DETERMINING MIXTURE CONDITIONS

Given a psychrometric chart and specific conditions relating to a given air-conditioning system, determine the heat load and tonnage of the system

Instructions to the Student:

Using a psychrometric chart and the below listed problem, plot the given information and make the necessary calculations to satisfy the problem.

Problem: An installation has a total air quantity of 10, 000 cfm. The return air quantity is 8, 000 cfm and the outdoor air quantity is 2, 000 cfm. Return air is supplied at 80 degrees dry bulb temperature and 62 degrees wet bulb temperature. Outdoor air is supplied at 90 degrees dry bulb temperature and 80 degrees wet bulb temperature. Find the mixed air temperature. Coil air is supplied at 45 degrees wet bulb temperature and 90% relative humidity. Find the total, sensible and latent heat of the air, the apparatus dewpoint of the coil, and make the calculations for coil capacity and bypass factor.

Procedure For Finding Mixed Air Temperature:

1. Plot the return air and outdoor air temperatures.
2. Draw a line between the two intersection points.
3. Determine the percentage of return air used by dividing the total return air quantity by the total air quantity.
4. Determine the temperature difference between the dry bulb temperatures of the outdoor air and return air.
5. Multiply the dry bulb temperature difference by the percent of return air.
6. Subtract the answer in Step 5 from the outdoor air dry bulb temperature.
7. Plot this temperature on the chart, extending up the dry bulb line to the line drawn in Step 2.

PART V

AIR VOLUME REQUIREMENT

Using heat load formula, determine the volume of air needed to condition a room to a specified temperature.

NOTE: The specified conditions and the hourly heat load for each room **are shown** on the building blueprint below.

FORMULA: $$\text{CFM} = \frac{\text{ROOM HEAT LOAD (Btu)}}{1.08 \times \text{TD}}$$

NOTE: This formula will determine the CFM needed to handle the **HOURLY HEAT LOAD** of each room.

DETERMINE THE CFM REQUIREMENT FOR EACH ROOM.

Using the specified conditions and given formula, compute the **CFM requirement** for each room.

ROOM A. ____________________

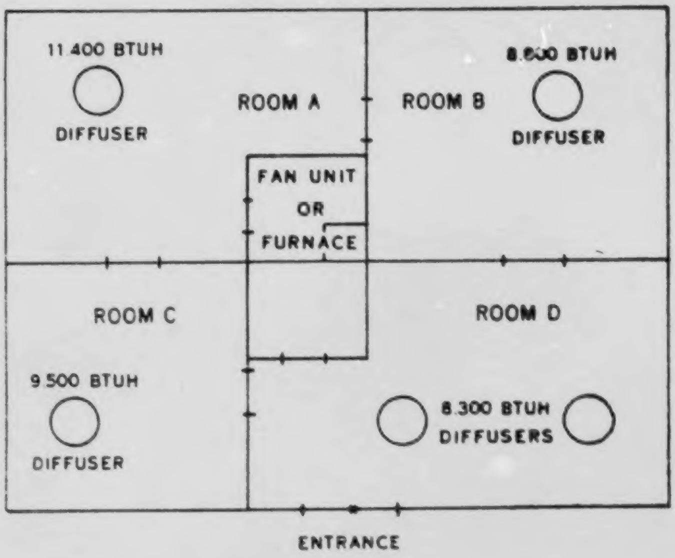
ROOM B. ____________________

ROOM C. ____________________

ROOM D. ____________________

ROOM DESIGN CONDITIONS - Based on the previously accomplished **load estimate.**

DUCT SIZE - Depends on the cost and the acceptable noise level in the **space.**


11,400 BTUH
DIFFUSER
ROOM A
ROOM B
8,600 BTUH
DIFFUSER
FAN UNIT
OR
FURNACE
ROOM C
ROOM D
9,500 BTUH
DIFFUSER
8,300 BTUH
DIFFUSERS
ENTRANCE

PART VI

DUCT SIZING

INSTRUCTIONS

Individual runs of duct will be run from the supply air plenum to the outlets, therefore each duct will be sized individually.

Use a "Ductulator" or chart to determine the size of duct that will carry the correct volume of air to the outlets without causing air noise above the acceptable level.

1. Fill in the chart shown below as to velocity, volume, and duct sizes.

ROOM	CFM	VELOCITY	MAIN DUCT	BRANCH DUCTS
FAN UNIT				▨
ROOM A				
ROOM B				
ROOM C				
ROOM D long				
ROOM D short				

2. Have the instructor check your work.

Checked by ______________________ ____
(Instructor)

PART VII

AIR FLOW BALANCING INSTRUMENTS

Determine air velocity and volume by using specific airflow instruments.

NOTE: The instructor will show you where the velocity readings should be taken.

USING MANOMETER AND PITOT TUBE

1. Connect the manometer and pitot tube for measuring velocity pressure in the duct.

   What is the velocity pressure (VP)? ____________________ H_2O.

2. Calculate the FPM.

   a. FPM = 4005 X $\sqrt{VP}$

   b. FPM = 4005 X ________

   c. FPM = ________

3. Measure the width and height of the duct.

   a. Width = ____________________."

   b. Height = ____________________."

   c. Area in sq in. = W ________ X H ________ = ________ **sq in.**

   d. Area in sq ft = area in sq in. ÷ 144 sq in. = ____________________ **sq ft.**

4. Figure the CFM.

   a. CFM = FPM X duct area (DA) in sq ft.

   b. CFM = ____________________ X ____________________ = ____________________.

5. From the table below, compute the data using the formulas listed in items **2-4**.

	Velocity Pressure	Duct Size	Duct Area	FPM	CFM
1.	.25	12" X 24"			
2.	.36	42" X 36"			
3.	.16	12" X 18"			
4.	.46	36" X 48"			
5.	.09	12" X 12"			

Checked by ____________________
(Instructor)

USING THE ANEMOMETER

1. Measure the height and width of the duct.

   a. Height = ________________________"

   b. Width = ________________________"

   c. Area in sq in. = W ____________ X H _______________ = ____________ sq in.

   d. Area in sq ft = Area in sq in. __________ ÷ 144 sq in. = _________ sq ft.

2. Divide the duct area into equal 6" square areas.

   a. Width = ____________________ 6" squares.

   b. Height = ___________________ 6" squares.

   c. W _________________ X H _________________ = ________________ Total equal 6" squares.

   To find elapsed time you will have to take a reading of 10 seconds at the center of each 6" square.

   d. Elapsed time = No. 6" squares ___________ X 10 seconds=__________seconds

   e. Elapsed time is _________________ seconds.

3. Using the anemometer to measure linear feet.

   a. After completing the measurement of the air, read the linear feet.

      (1) The left dial reads ____.

      (2) The right dial reads ____.

      (3) The central dial reads ____.

      (4) What is the anemometer reading ________________________________.

4. Convert the anemometer reading to FPM.

   a. FPM = AR X 60 ÷ ET

   b. FPM = _________________ X 60=__________________ ÷ ________________

      ET = _________________

   c. FPM = _______________________

5. Determine the CFM

a. CFM = FPM X DA

b. CFM = ____________ X ____________ = ______________

c. CFM = ______________________

6. From the table below, compute the data using the formulas in steps 1-5.

	Anemometer Reading	Duct Size	Duct Area	Elapsed Time	FPM	CFM
1.	1350	42" X 12"				
2.	889	24" X 12"				
3.	1350	48" X 12"				
4.	1200	24" X 12"				
5.	1500	30" X 18"				

Checked by ________________________
(Instructor

USING THE VELOMETER

1. Attach testing probes to velometer.

2. Use the velometer to find the FPM.
You will have to average the readings.

a. Reading 1 ________________
b. Reading 2 ________________
c. Reading 3 ________________
d. Reading 4 ________________
e. Reading 5 ________________
f. Reading 6 ________________
g. Reading 7 ________________
h. Reading 8 ________________

Total of readings a through h = ____________________________

Number of readings = __________________________________

Average of readings = Total ÷ Number

FPM = ________________________

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3. Figure the duct area.

   a. Width in inches = ______________________________

   b. Height in inches = ______________________________

   c. Duct area in sq in. = ______________________________

   d. Duct area in sq ft = sq in. ÷ 144 sq in.

   e. DA ________________ sq in. ÷ 144 sq in. = ________________

   f. DA ______________________________

4. Figure the CFM

   a. CFM = FPM X DA

   b. CFM = ____________ X ________________ = ____________

   c. CFM = ________________

5. From the table below, compute the data using the formulas in steps 1 through 4.

	Velometer Average Reading	Duct Size	Duct Area	FPM	CFM
1.	500	12" X 12"			
2.	750	12" X 18"			
3.	1000	18" X 18"			
4.	1820	24" X 24"			
5.	2400	36" X 36"			
6.	1280	24" X 30"			

Have the instructor check your work.

Checked by ______________________________
(Instructor)

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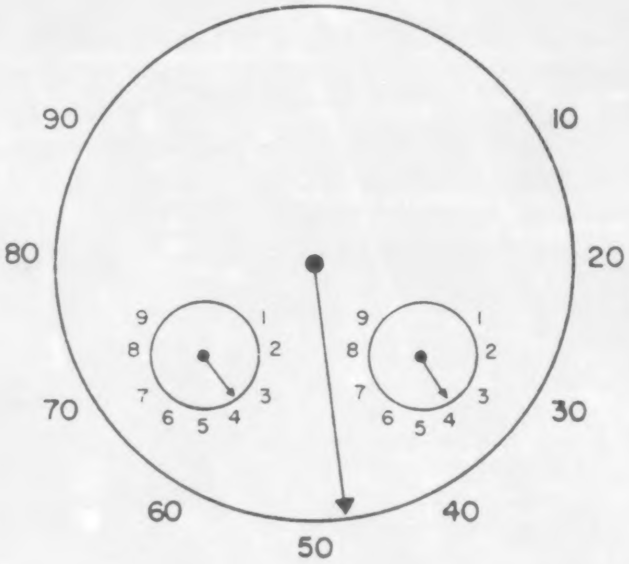
Questions:

1. What is the purpose of a velometer?

2. When using a manometer to measure total pressure, the total pressure may be found by adding the velocity pressure and the ________________ pressure.

3. In the figure below the anemometer is indicating ________________ linear feet of air movement.


10
20
30
40
50
60
70
80
90
9
1
8
2
7
3
6
5
4
9
1
8
2
7
3
6
5
4

Checked by ______________________________
(Instructor)

PART VIII

AIR FLOW BALANCING (GENERAL PROCEDURE)

Utilize a method for balancing airflow to meet the requirements as determined previously.

NOTE: The velometer will be used to measure the airflow.

1. Position dampers and room diffusers to obtain maximum airflow.
2. Check and list the CFM requirements as determined for each room.

A. ________________ B. ______________ C. ________________ D. ______________

3. Determine existing CFM to each of the rooms.

A. ________________ B. ______________ C. ________________ D. ______________

4. Adjust balancing dampers to obtain the airflow that is closer to the required CFM.

NOTE: This step must be repeated several times because each damper adjustment will affect the airflow to the other rooms.

5. List the CFM as you make a round of adjustments.

A. ________________ B. ______________ C. ________________ D. ______________

6. Continue making adjustments until the required CFM is obtained for each room.
7. List your final results.

A. ________________ B. ______________ C. ________________ D. ______________

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-2-P1

OPERATE AND SERVICE WINDOW AIR CONDITIONING

OBJECTIVE

Upon completion of this project you will be able to:

1. Identify major components and trace refrigerant and air flow through a window air conditioning unit.
2. Perform preoperational checks of window air conditioning units.
3. Operate window air conditioning units.
4. Troubleshoot window air conditioning unit malfunctions.
5. Service window air conditioning units.

Standard of performance

The standard of performance for this project is 100 percent completion, errorfree

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-2-P1	1/student
Trainer, Window air conditioner	1/2 students
Pen or pencil	1/student

PROCEDURE

1. Locate the following units:

   a. Fan motor
   b. Evaporator fan
   c. Condenser fan
   d. Evaporator
   e. Condenser
   f. Air filter
   g. Thermostat
   h. Selector switch
   i. Metering device
   j. Compressor

2. Fill in the blanks:

   a. Compressor: phase ____________________, voltage ____________________.

      running amps __________________ and compressor capacity _____________.

   b. Evaporator fan motor hp __________________, voltage __________________.

      running amps ________________________.

   c. Manufacturer of unit ____________________________.

   d. Charge __________________ lb of refrigerant _____________________________.

   e. Test pressure __________ psi low side, ________________ psi high side.

3. Start at the compressor and trace the flow of refrigerant through the system.

4. Start at the filter and trace the flow of air through the system.

5. Perform preoperational checks

   a. Disconnect the power cord.

   b. Remove cover.

   c. Check fans for freedom of movement.

   d. Check security of mounting of components.

   e. Inspect filter.

6. Operation.

   a. Be sure that the thermostat is in the OFF position.

   b. Plug in the unit and turn the blower to LOW FAN.

   c. Allow the fan to operate for 30 seconds.

   d. Turn selector switch to LOW COOL.

      NOTE: Compressor may not operate due to low ambient temperature.

   e. Adjust thermostat to bring compressor on.

   f. Allow compressor to operate for approximately three minutes.

   g. Determine supply air temperature __________________ __ degrees.

   h. Turn selector switch to HIGH COOL and operate for approximately three minutes.

i. Determine supply air temperature ______________ degrees.

j. Turn selector switch to OFF.

NOTE: Wait at least two minutes before attempting to restart.

WHY? ______________

k. Unplug unit.

7. Trouble Diagnosis

a. Insufficient cooling

(1) Probable causes

____

____

____

(2) Remedy

____

____

____

b. Compressor will not start.

(1) Probable causes

____

____

____

(2) Remedy

____

____

____

c. Fan motor will not operate.

(1) Probable causes

____

____

____

(2) Remedy

____

____

____

d. Use diagnostic chart to check window unit for common malfunctions.

e. Install manifold gage assembly and check system for abnormal low and high side pressures and indications of restricted refrigerant lines.

8. Inspection, Maintenance, and Installation

a. Inspection

NOTE: All power OFF.

(1) Unplug power cord.

(2) Check fan bearings for lubrication.

(3) Clean or replace filter as necessary.

(4) Check unit for cleanliness, clean if necessary.

(5) Check condition of evaporator and condenser fins, straighten if necessary.

b. Maintenance and Installation.

(1) Servicing and replacing fans:

(a) Check direction of rotation.

(b) Check and clean blade to assure design airflow.

(c) Replace damaged fan with one that moves same air volume.

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1 How does incorrect air volume affect the system performance?

2 Will a higher fan speed overload the motor? ________

3 What should be considered when replacing the fan motor?

c. Window unit installation:

(1) The back of the unit should be 1/2" - 1/4" lower than the front to allow ________.

(2) If the power cord that is supplied with the unit is not long enough, what precaution should be taken?

(3) What type power receptacle would be used with the following voltage and amperate ratings?

(a) All 115v units ________.

(b) 208-230v, 0-12 amps ________.

(c) 209-230v, 12.1-16 amps ________.

NOTE: In accordance with National Electrical Code, the maximum allowable current on a 15-amp circuit is 12 amps. Normal ratings for 115v air conditioners will not exceed 12 amps.

(4) In reference to the above note, why are window air conditioners connected to a separately fused circuit?

____

____

d. Charging Procedures:

NOTE: All power OFF.

(1) Data Plate Information. Type of refrigerant ______________, voltage ______________, FLA ______________, amount of charge ______________.

(2) Evacuate system, inches of vacuum ______________.

(3) Add refrigerant to minimum pressure of 60 psi.

(4) Leak check system. Leaks: YES ____________ NO ____________.

NOTE: Turn power ON.

(5) Start unit compressor and monitor the pressures.

(6) Restrict the condenser airflow so as to create a discharge pressure equivalent to outdoor conditions. (This will simulate actual operating discharge pressures and cause correct refrigerant flow through capillary tube.)

(7) Continue to charge until a 40-degree evaporator is reached. (CAUTION: If entering air is below 80 degrees, a forty-degree evaporator may not be reached without overcharging.)

(8) Pressures __________ psi high side __________ psi low side.

NOTE: Pressure on high side should still be equivalent to outdoor conditions plus thirty degrees heat of compression.

(9) Check running amperage __________ FLA. (This may be low due to low entering air temperature.)

(10) What is the temperature difference? ______________ __. (Normal temperature difference is twenty degrees.)

Checked by ______________________
(Instructor)

OPERATE AND ELECTRICALLY TROUBLESHOOT RESIDENTIAL AIR CONDITIONING

OBJECTIVE

Upon completion of this project you will be able to:

1. Perform preoperational checks of residential units.

2. Operate a residential unit.

3. Perform shutdown of a residential unit.

4. Troubleshoot residential air conditioning unit electrical systems.

Standard of performance

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-2-P2	1/student
Trainer, residential air conditioner	1/12 students

PROCEDURE

1. Perform preoperational check.

   a. Cooling cycle.

      (1) Check power source.

      NOTE: Crankcase heater must be in operation at least 12 hours prior to operation.

         (a) What is the function of the crankcase heater? ____________________

         ____

      (2) Heat-Cool switch OFF.

      (3) Turn gas supply valve OFF. NOTE: The gas supply is left ON when the heating-cooling system features automatic changeover.

      (4) Check return air grille and filter for obstructions and cleanliness.

      (5) Check condenser fins for obstructions.

b. Heating cycle.

  (1) Heat-Cool switch OFF.

  (2) Turn main gas supply ON.

  (3) Check for gas leaks.

  (4) Check flue for obstructions.

  (5) Light the pilot.

  (6) Check return air grille and filter for obstruction and cleanliness.

2. Perform starting procedures.

  a. Select heat or cool.

  b. Select fan automatic or manual position.

  c. Set thermostat for desired temperature.

  d. Check operation of system.

3. Accomplish operational checks.

  a. Observe burner flame and adjust accordingly if in heating.

  b. Observe refrigerant sight glass if in cooling.

  c. Check unit for unusual noise or excessive vibration.

  d. Check supply air for proper flow and air distribution.

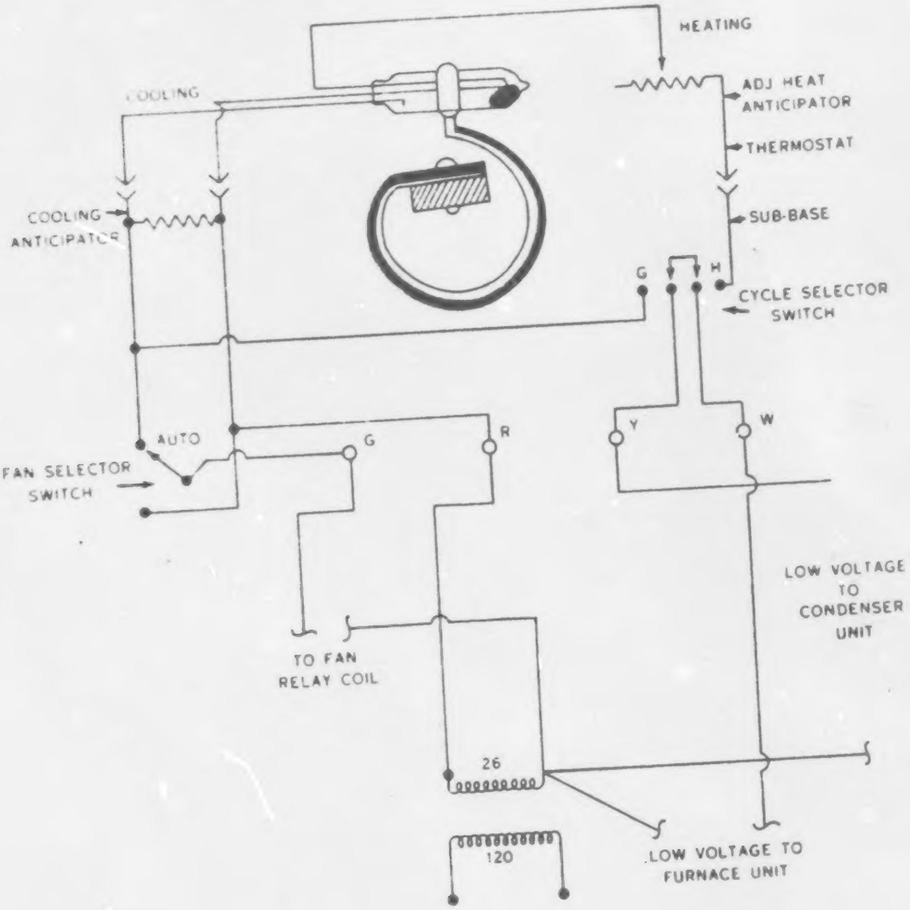
  e. Check wet bulb and dry bulb temperature of supply air.

4. Accomplish shutdown procedures.

  a. Turn heat-cool selector switch to OFF.

  b. Turn main gas valve OFF.

5. Using diagram below, identify the components controlled by the thermostat according to color coded wiring.


HEATING
COOLING
ADJ HEAT ANTICIPATOR
THERMOSTAT
COOLING ANTICIPATOR
SUB-BASE
G
H
CYCLE SELECTOR SWITCH
AUTO
G
R
Y
W
FAN SELECTOR SWITCH
LOW VOLTAGE TO CONDENSER UNIT
TO FAN RELAY COIL
26
120
LOW VOLTAGE TO FURNACE UNIT

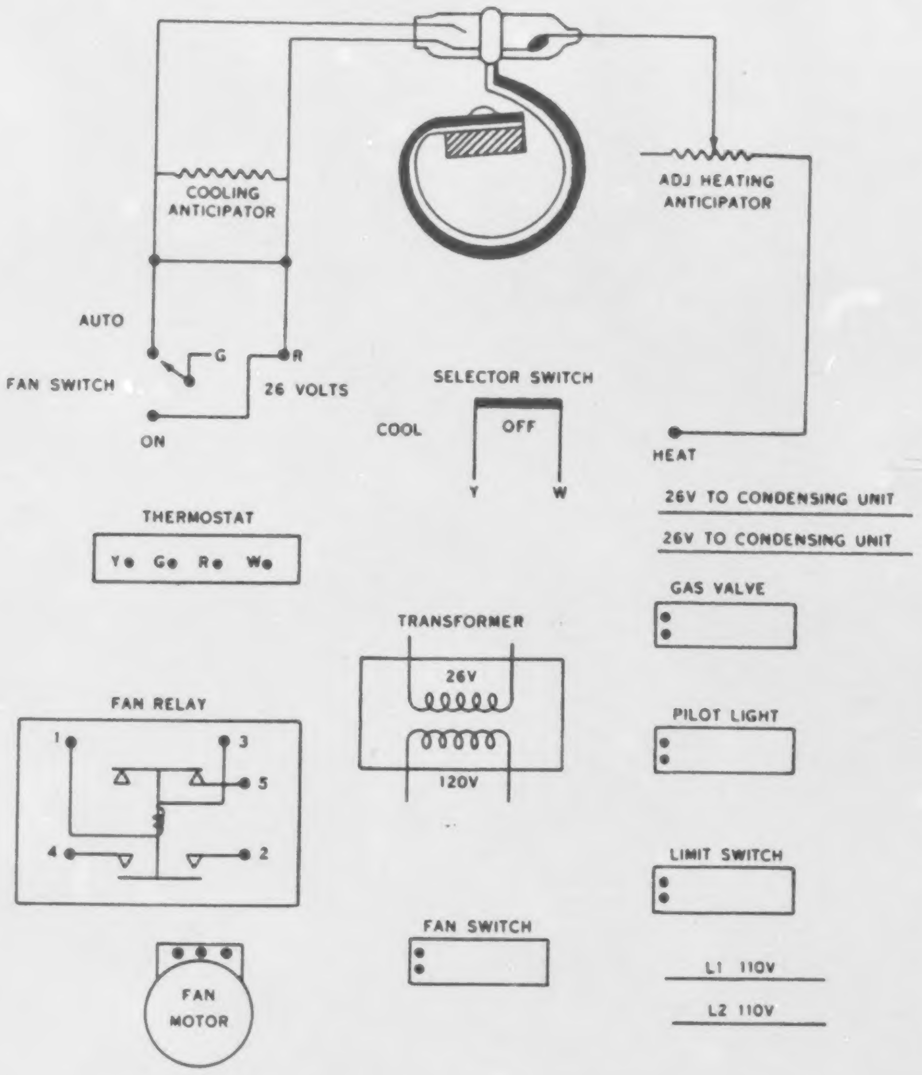
Low Voltage Thermostat

a. Terminal G. ______________________________

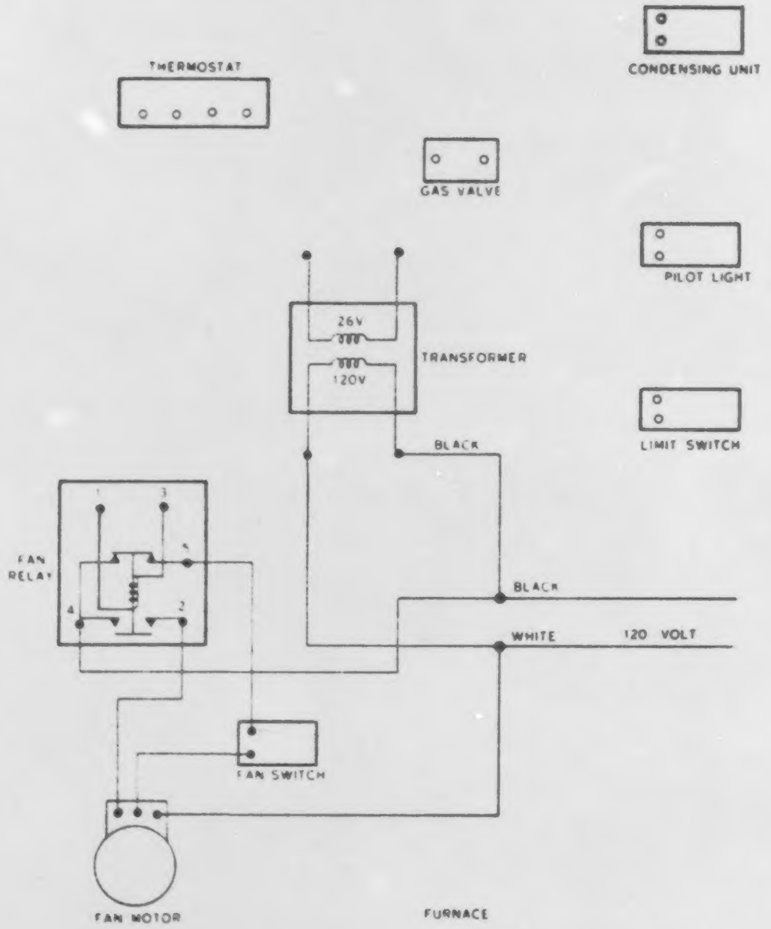
b. Terminal Y. ______________________________

c. Terminal W. ______________________________

6. Complete the following wiring diagrams.


COOLING ANTICIPATOR
ADJ HEATING ANTICIPATOR
AUTO
G
R
FAN SWITCH
26 VOLTS
ON
SELECTOR SWITCH
COOL
OFF
HEAT
Y
W
26V TO CONDENSING UNIT
26V TO CONDENSING UNIT
THERMOSTAT
Y G R W
GAS VALVE
TRANSFORMER
26V
120V
PILOT LIGHT
FAN RELAY
1
3
5
4
2
LIMIT SWITCH
FAN SWITCH
FAN MOTOR
L1 110V
L2 110V

Heating/Cooling Thermostat Wiring


THERMOSTAT
CONDENSING UNIT
GAS VALVE
PILOT LIGHT
26V
120V
TRANSFORMER
LIMIT SWITCH
BLACK
FAN RELAY
1
3
4
2
BLACK
WHITE
120 VOLT
FAN SWITCH
FAN MOTOR
FURNACE

Furnace and Condensing Unit Wiring

7. Use the following wiring diagram and list of symptoms, with meter readings, to identify the problems.

SYMPTOMS	METER READINGS	PROBLEM
Control relay inoperative thermostat closed	24V ac across control relay, 0V ac across thermostat	
Control relay inoperative	HP control 0V ac, LP control 220V ac	
Unit will not start	Y to C 0V ac, R to C 24V ac	
Unit hums, cycles on overload	Relay contact 2 to 5-10 ohms start cap 0 ohms	
Unit stays on start winding	Relay contacts 1 to 2-0 ohms, 2 to 5-infinity ohms	
Unit runs hot	All voltmeter and ohmmeter readings OK	
Comp noisy on start up but runs quiet	All readings seem OK	
Unit will not start	L1 to (L2) 220V ac, HP and LP control to ground 110V ac, control relay 220V ac	

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Checked by ______________________
(Instructor)

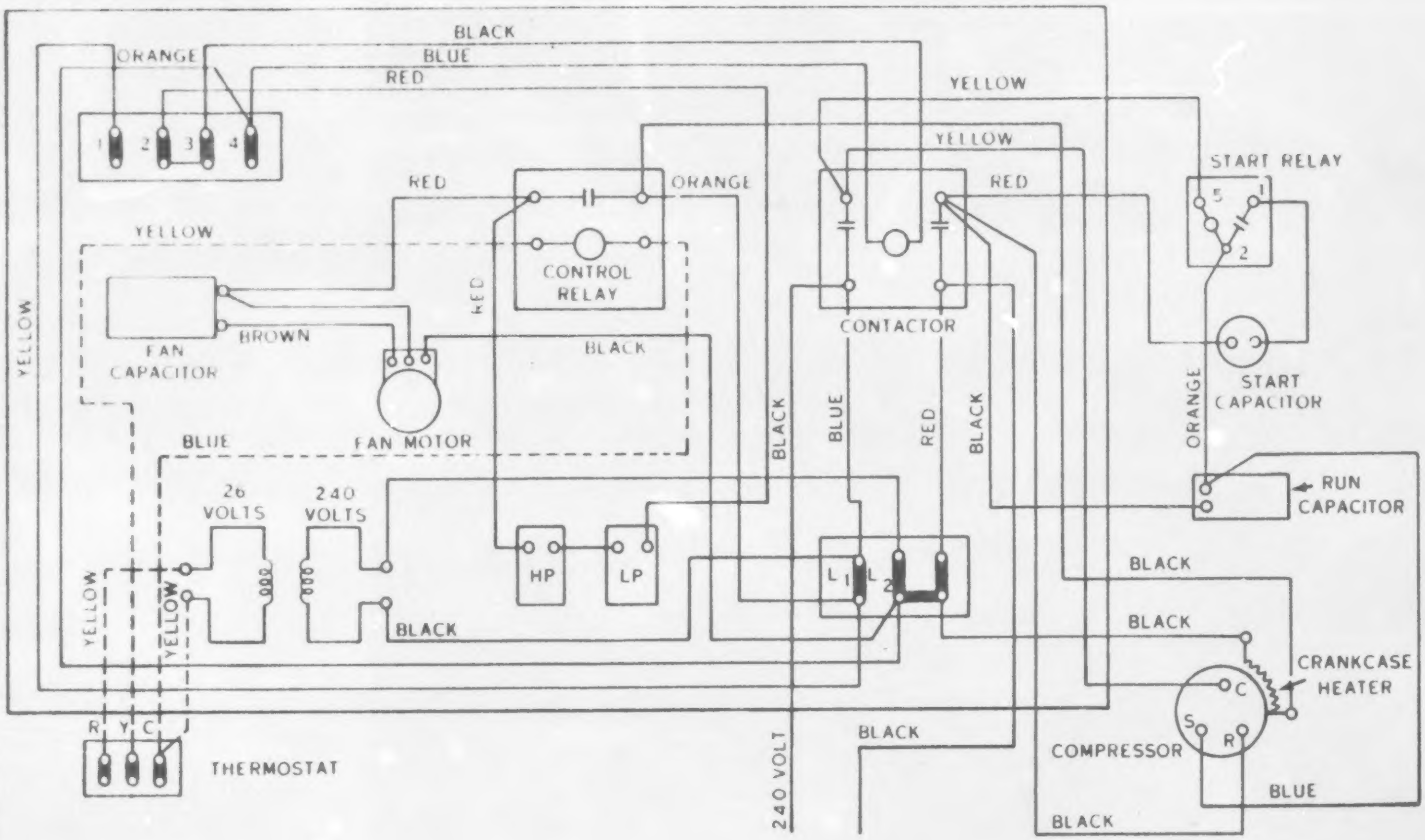
BLACK
ORANGE
BLUE
RED
YELLOW
1
2
3
4
YELLOW
START RELAY
5
1
2
RED
ORANGE
RED
YELLOW
CONTROL RELAY
CONTACTOR
FAN CAPACITOR
BROWN
BLACK
RED
FAN MOTOR
START CAPACITOR
ORANGE
BLACK
BLUE
RED
BLACK
YELLOW
BLUE
26 VOLTS
240 VOLTS
RUN CAPACITOR
HP
LP
L1
L2
BLACK
BLACK
YELLOW
YELLOW
BLACK
BLACK
CRANKCASE HEATER
C
S
R
COMPRESSOR
R
Y
C
THERMOSTAT
240 VOLT
BLACK
BLUE
BLACK

Figure 2. Condensing Unit Wiring

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-3-P1

CENTRIFUGAL REFRIGERATION COMPONENTS AND CYCLE

OBJECTIVE

Upon completion of this project you will be able to:

1. Identify major components of a centrifugal machine.
2. Plot the flow of refrigerant through a centrifugal machine and determine the state of the refrigerant through each component.

Standard of performance

	Basis of Issure
WB 3AZR54550-2-III-3-P1	1/student
Trainer, 100-Ton centrifugal	1/12 students
Pen or pencil	1/student

PROCEDURE

1. Refer to the following schematic and use the following letters to identify the major components.

   a. Condenser

   b. Economizer

   c. Evaporator

   d. Compressor

   e. Suction damper

   f. Economizer vapor line

   g. hot gas bypass

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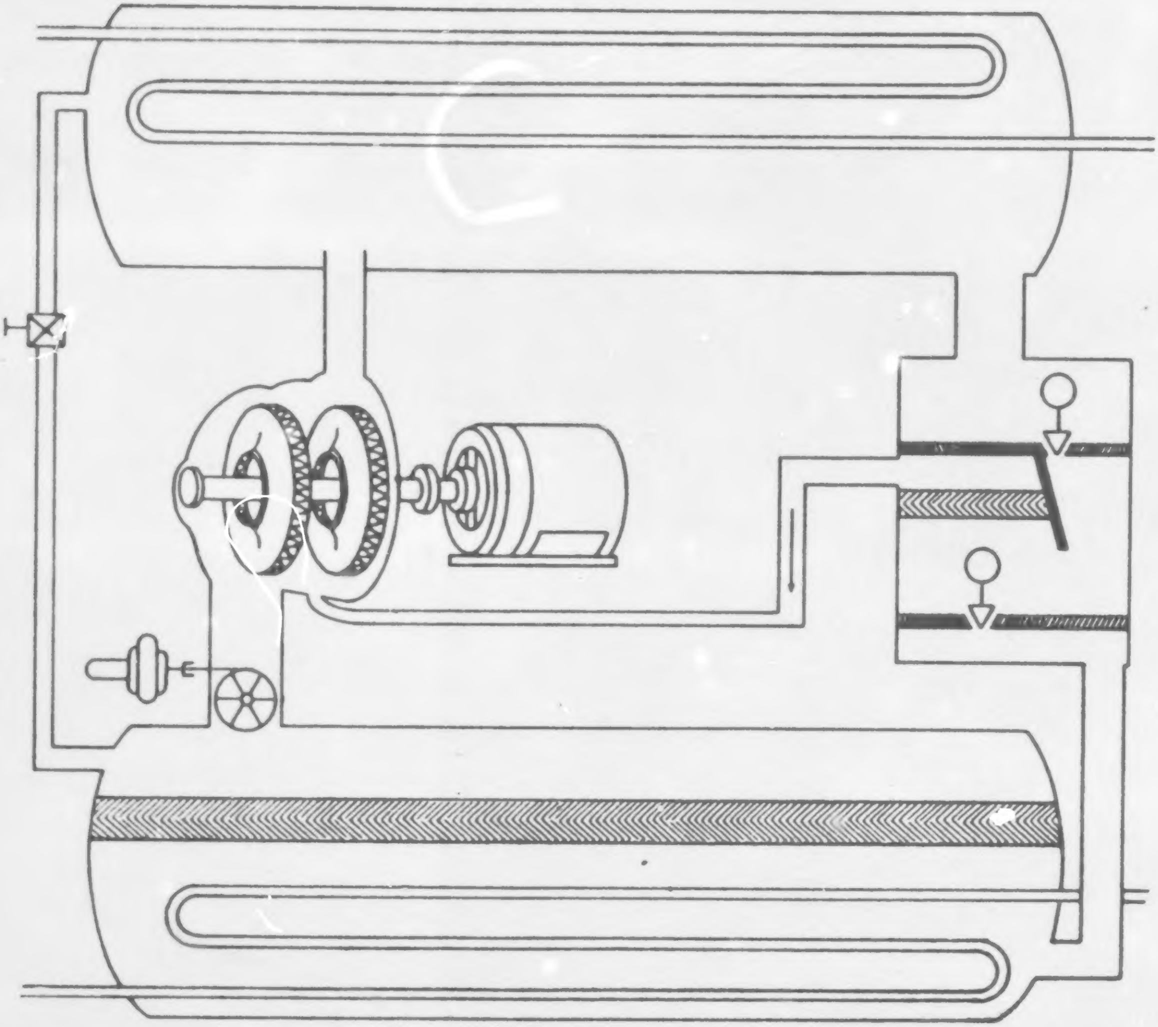

CMK-015

Centrifugal Machine Schematic

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2. Refer to the schematic, and with the following color code, trace the flow of refrigerant through the centrifugal system.

   a. Low pressure vapor ---------- light blue

   b. Low pressure liquid ---------- dark blue

   c. High pressure vapor --------- light red

   d. High pressure liquid --------- dark red

   e. Medium pressure vapor ------ light green

   f. Medium pressure liquid ------ dark green

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-3-P2

CENTRIFUGAL REFRIGERATION CAPACITY CONTROL

OBJECTIVES

Upon completion of this project you will be able to:

1. Locate and identify the types and individual components of a centrifugal machine capacity control system.
2. Give the functions of the control system components.
3. Explain the operation of the actual control system.

Standard of performance:

The standard of performance of this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-3-P2	1/student
Trainer, Air Conditioning, 100 ton centrigugal	1/12 students
Pen or pencil	1/student

PROCEDURE

PART I

METHODS OF CAPACITY CONTROL ON CENTRIFUGAL MACHINES

INSTRUCTIONS

Answer the questions that follow by filling in the blanks.

1. What method of capacity control is used on open types of centrifugal machines?

____

2. List the methods of speed control used with centrifugal machines.

   a. _______________________________________

   b. _______________________________________

   c. _______________________________________

3. What is the most common method of capacity control used on hermetic centrifugal machines? _______________________________________

4. List the methods of refrigerant flow control.

   a. ______________________________

   b. ______________________________

5. What method of capacity control will reduce the machines cooling capacity below 40 percent without requiring the use of hot gas? ______________________________

   ____

6. Which method of capacity control requires the most power input to the machine at any reduced load? ______________________________

   ____

7. Which method of capacity control is the most economical at loads above 40 percent capacity? ______________________________

   ____

8. Which method of capacity control features a corresponding reduction in power consumption as the capacity control system reduces the machine capacity below 40 percent load. ______________________________

9. When the suction damper or the inlet guide vanes start closing, does the refrigerant gas volume entering the compressor inlet, for a given load, increase or decrease?

   ______________ EXPLAIN: ______________________________

   ____

   ____

   ____

10. What happened to the specific volume of the gas as it leaves the damper or inlet guide vanes to enter the compressor? ______________________________

    ____

    ____

11. What happens to the mass flow rate of the refrigerant when either the damper or inlet guide vanes move toward the closed position? ______________________________

____

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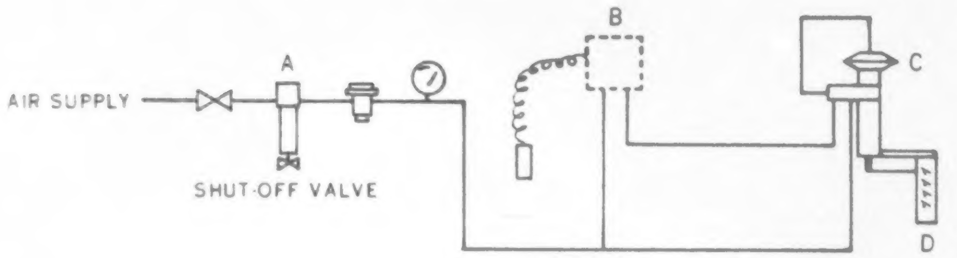
PART II

CENTRIFUGAL SYSTEM TRAINER CAPACITY CONTROL SYSTEMS

1. SUCTION DAMPER SYSTEM

INSTRUCTIONS: Identify the components of a capacity control system as shown in the diagram below and then give the function and operation of each of the components.



Components

a. (Function) ____________________

____

____

(Operation) ____________________

____

____

b. (Function) ____________________

____

____

(Operation) ____________________

____

____

c. (Function) ______________________________

____

____

(Operation) ______________________________

____

____

d. (Function) ______________________________

____

____

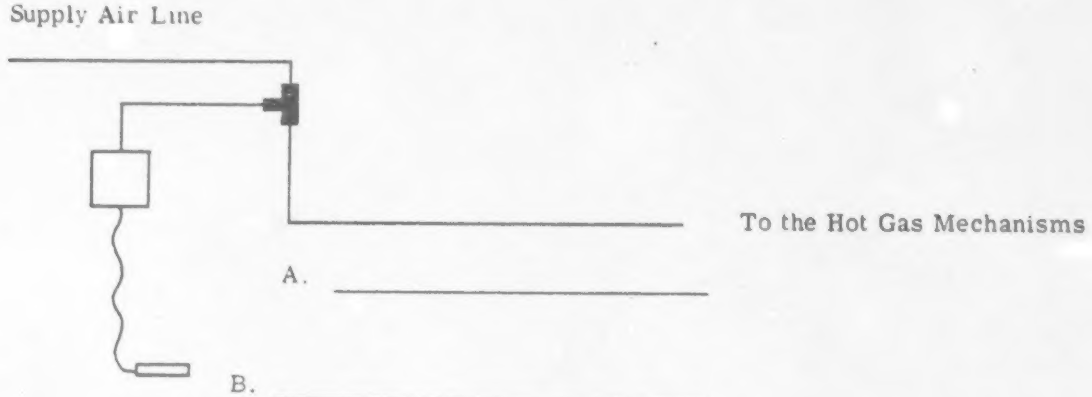
(Operation) ______________________________

____

____

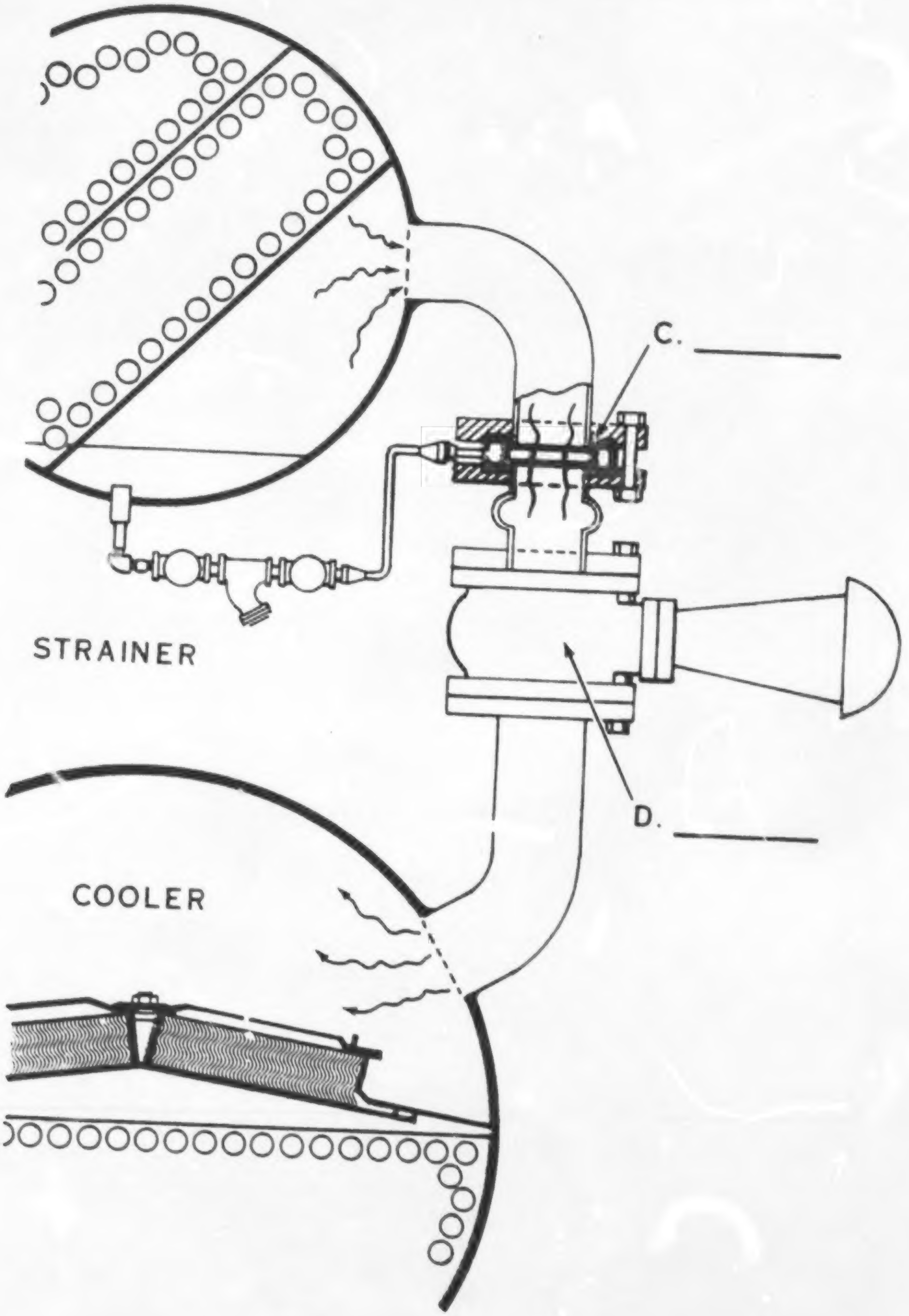
2. HOT GAS BY-PASS SYSTEM

INSTRUCTIONS: Identify the components of a hot gas bypass system as shown in the diagram that follows and then give the function and operation of each of the components.


Supply Air Line
To the Hot Gas Mechanisms

A. ______________________________

B. ______________________________


STRAINER
COOLER
C. ________
D. ________

Automatic Hot-Gas BYPASS System

338

Components

a. (Function) ______________________________

____

____

(Operation) ______________________________

____

____

____

b. (Function) ______________________________

____

____

(Operation) ______________________________

____

____

____

c. (Function) ______________________________

____

____

(Operation) ______________________________

____

____

____

d. (Function) ______________________________

____

____

(Operation) ____

TROUBLESHOOTING CENTRIFUGAL SYSTEMS

OBJECTIVE

Upon completion of this project you will be able to:

List the possible cause and give the remedy for centrifugal system failures.

Standard of performance:

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-3-P3	1/student
Pen or pencil	1/student

PROCEDURE

In the spaces below list at least one cause and remedy for the given problems.

1. Trouble - High Condenser Pressure

Cause ____

Remedy ____

2. Trouble - Chilled Water Temperature Too High

Cause ____

Remedy ____

3. Trouble - Chilled Water Temperature Too Low

Cause ____

Remedy ____

4. Trouble - Condenser Pressure Too Low

Cause ____

Remedy ____

5. Trouble - Oil Temperature Too Low

Cause ______

Remedy ______

6. Trouble - Oil Temperature Too High

Cause ______

Remedy ______

7. Trouble - Purge System Inoperative

Cause ______

Remedy ______

8. Trouble - Excessive Refrigerant Loss

Cause ______

Remedy ______

9. Trouble - Compressor Will Not Start

Cause ______

Remedy ______

Checked by ______
(Instructor)

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

ABSORPTION REFRIGERATION COMPONENTS AND CYCLE

OBJECTIVE

Upon completion of this project you will be able to:

1. Identify major components of an absorption system.
2. Locate the major components of an absorption machine.
3. Give the function of all required components, pumps, lines, and accessories.
4. Trace the cycle o system fluids flow

Standard of performance

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-4-P1	1/student
Pencils, set, colored	1/student

PROCEDURE

1. Using the schematic diagram below and the list of components, write the number of the component in the parenthesis next to the name of the component and state its function.

( ) Evaporator

( ) Absorber

( ) Condenser

( ) Refrigerant Pump

( ) Heat Exchanger

( ) Steam Lines

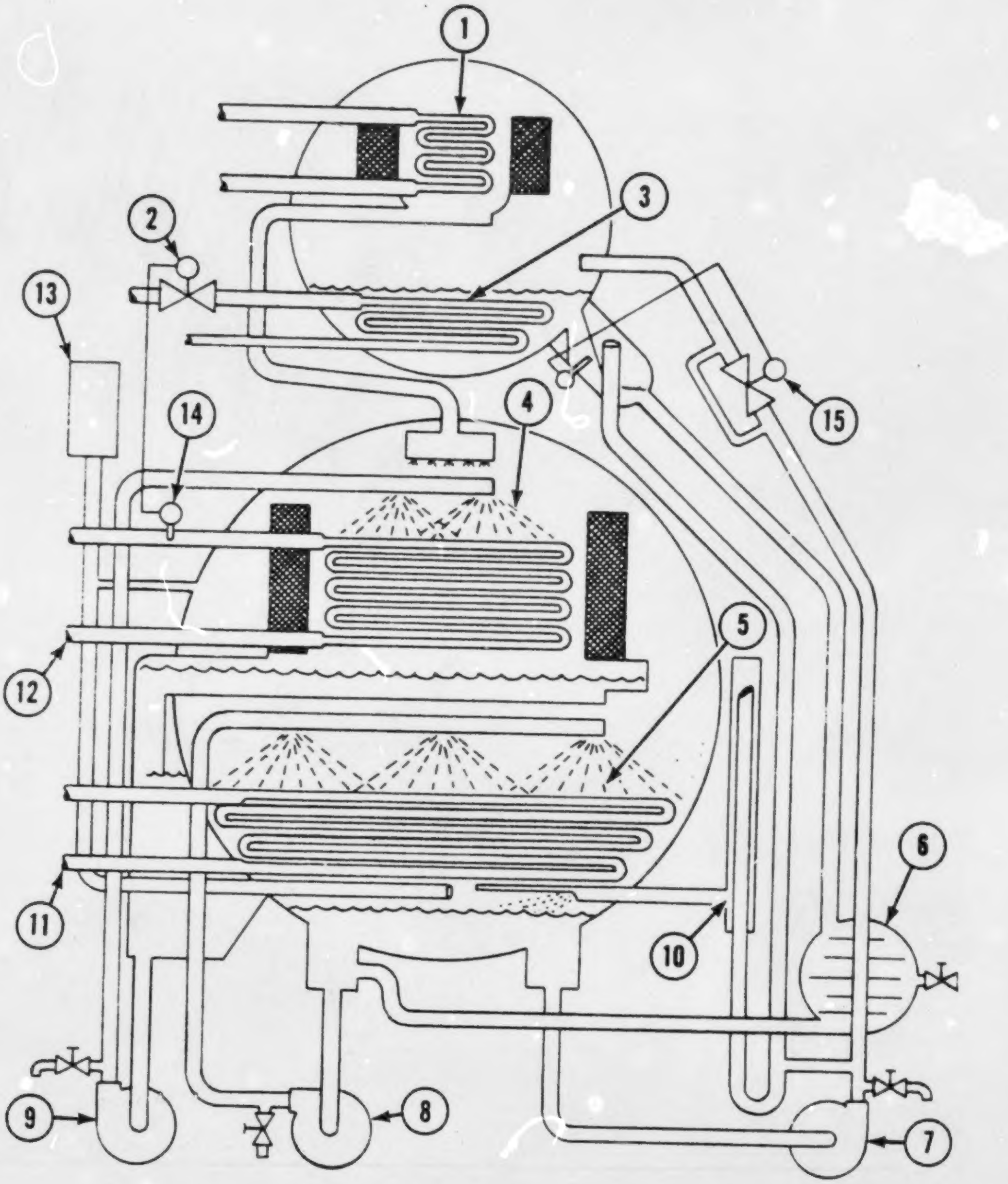
( ) Decrystallization Line

( ) Absorber Pump

( ) Flush Line

( ) Purge Chamber

( ) Generator Pump


1
2
3
13
14
4
15
12
5
6
11
10
9
8
7

C-MA-029

Absorption System

2. Using the following color code trace the flow of lithium bromide, refrigerant and other solutions through the system.

   a. Condenser water - blue

   b. Steam - Red

   c. Refrigerant - Green

   d. Strong solution - Yellow

   e. Weak solution - Yellow/Green

3. What is the purpose of the flush line?

4. What is the purpose of the heat exchanger?

5. What is the purpose of the condenser water bypass valve?

Checked by ______________________
(Instructor)

SERVICING ABSORPTION SYSTEMS

OBJECTIVE

Upon completion of this project you will be able to:

1. State the procedures for performing a standing vacuum test.
2. State the procedures for performing a running vacuum test.
3. State the procedures for performing a leak test.
4. State the procedures for charging refrigerant and absorbant.
5. State the procedures for determining the solution concentration.

Standard of performance:

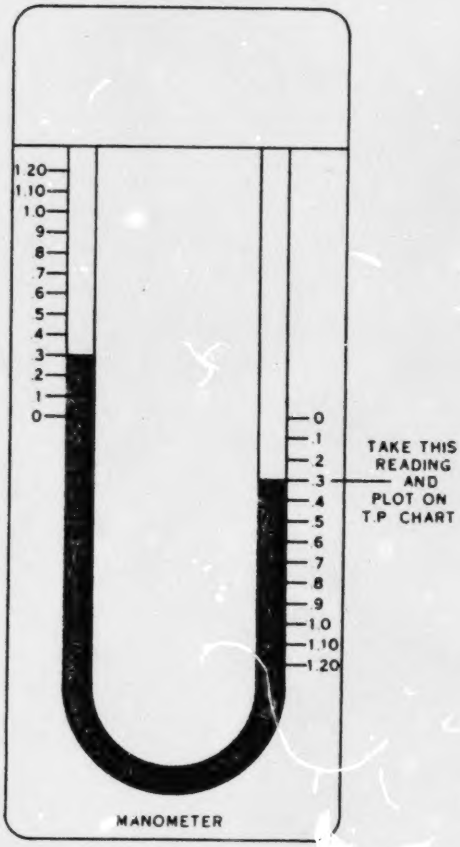
The standard of performance for this project is 100 percent, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-4-P2	1/student
Pen or pencil	1/student

PROCEDURE

1. Refer to vacuum indicator drawing.
2. To determine the quality of the machine vacuum, you must log the ______________ reading.
3. This test requires a ______________ hour waiting period.
4. The maximum rise in pressure allowed is ______________ above the previous reading.


1.20
1.10
1.0
9
8
7
6
5
4
3
2
1
0
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.10
1.20
TAKE THIS READING AND PLOT ON T.P CHART
MANOMETER

Vacuum Indicator

5. Refer to the following drawings to answer questions no. 6 through 16.

6. On the left is a picture of a ______________________________.

7. On the right is a picture of a ______________ - ________________

8. To determine the quality of the vacuum, two things must be known; the ambient ________________ and the present ________________ readi

9. The maximum allowable pressure above the curve is __________ of one inch of vacuum.

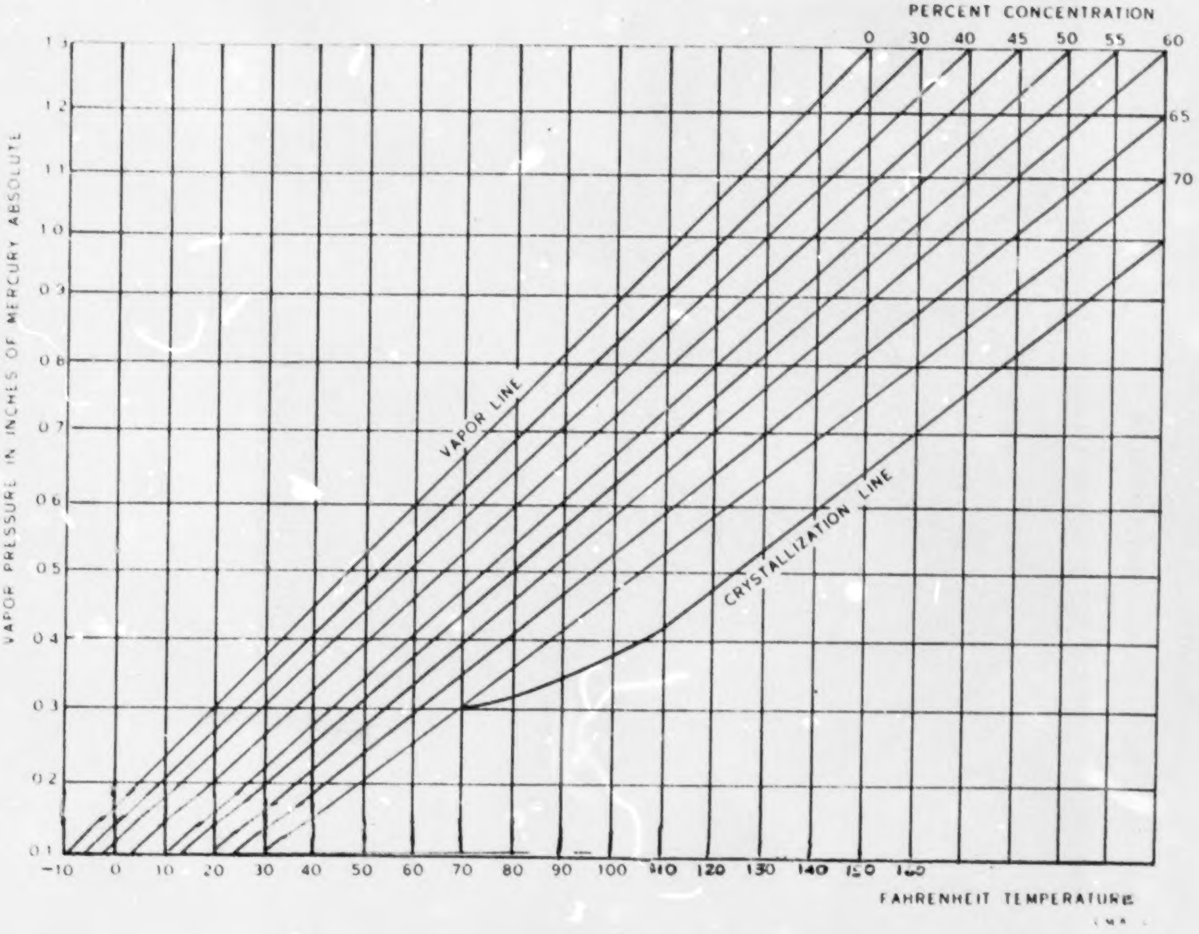
10. The curve on the P-T chart represents the corresponding increase in pressure for each increase in ______________________________________.

22. To use this chart, we must know the temperature of the refrigerant leaving the ____________________ and the temperature of the ______________________ ________________ leaving the ____________________.

23. With a leaving refrigerant temperature of 110° and a leaving solution temperature of 170°, the solution concentration would be ________________ percent.

24. With a leaving refrigerant temperature of 70° and a leaving solution temperature of 175° we can expect the lithium bromide solution to be ____________________.

25. If the leaving solution temperature was 160° and the condenser water was too cold causing the temperature of the refrigerant leaving the condenser to be 75°, the solution would be ____.



Solution Chart

Checked by ______________________
(Instructor)

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-4-P3

ABSORPTION ELECTRICAL SYSTEMS

OBJECTIVE

Upon completion of this project you will be able to:

1. Schematically draw the control and load circuits of an absorption machine.
2. Name the components of the absorption machine electrical system.

Standard of performance

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-4-P3	1/student
Pen or pencil	1/student

PROCEDURE

1. Refer to the schematic diagram below.
2. Identify the following components:

(1) ____________________

(2) ____________________

(3) ____________________

(4) ____________________

(5) ____________________

(6) ____________________

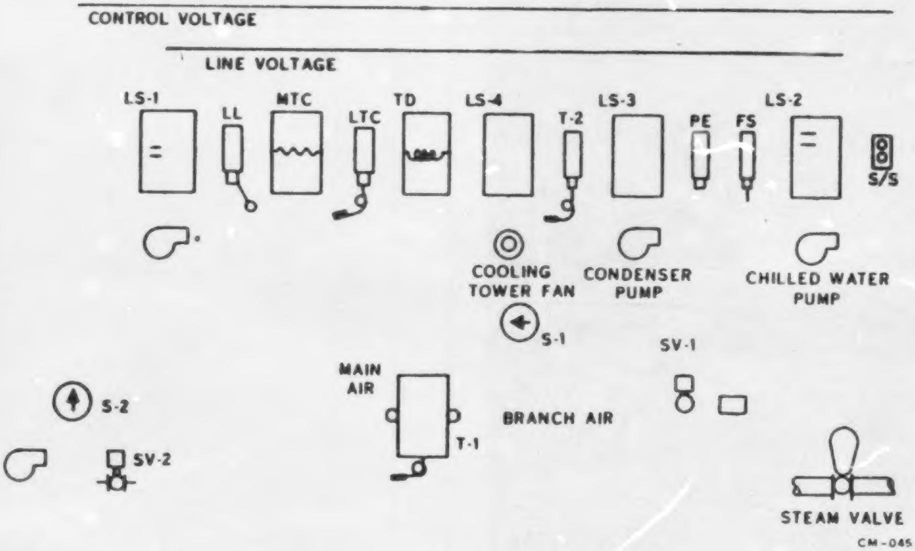
(7) ____________________

(8) ____________________

(9) ____________________

(10) ____________________

3. Draw lines connecting all components in the Line Voltage Circuit.
4. Draw lines connecting all components in the Control Voltage Circuit.
5. Have the instructor check your work.


CONTROL VOLTAGE
LINE VOLTAGE
LS-1
LL
MTC
LTC
TD
LS-4
T-2
LS-3
PE
FS
LS-2
S/S
COOLING TOWER FAN
CONDENSER PUMP
CHILLED WATER PUMP
S-1
SV-1
MAIN AIR
BRANCH AIR
T-1
S-2
SV-2
STEAM VALVE
CM-045

Checked by ______________________
(Instructor)

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-4-P4

ABSORPTION SYSTEM CAPACITY CONTROLS

OBJECTIVE:

Upon completion of this project you will be able to adjust and calibrate the Honeywell RP 908A controller and LP 914A sensor capacity control system.

Standard of performance:

The standard of performance for this project is 100 percent completion and adjustment of the capacity control system to an accuracy of ± 4°F.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-4-P4	1/student
Trainer, Refrigeration Controls	1/2 students
Controller RP 908A	1/2 students
Sensor LP 914A	1/2 students

PROCEDURE

PART I

Accomplish all preoperational checks listed prior to operating trainer.

1. Preoperational checks.
   a. Close all air line valves.
   b. Check Master Switch for ON position.
   c. Check Air Compressor Switch for ON position.

2. Connect the control loop as shown on following page.

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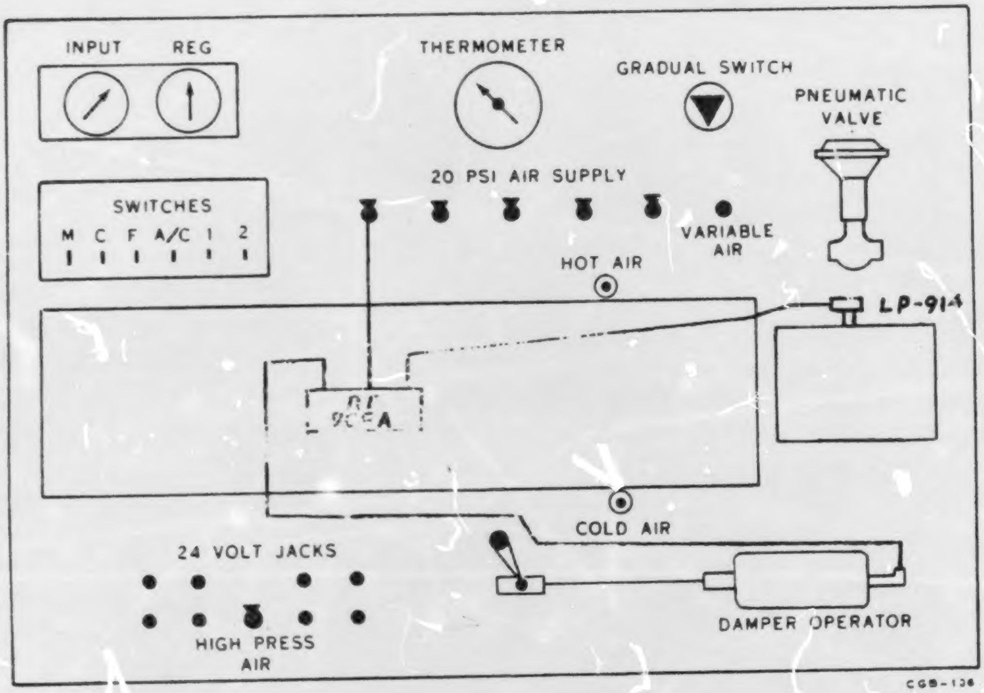
INPUT
REG
THERMOMETER
GRADUAL SWITCH
PNEUMATIC VALVE
SWITCHES
M C F A/C 1 2
20 PSI AIR SUPPLY
VARIABLE AIR
HOT AIR
LP-914
RC 905A
COLD AIR
24 VOLT JACKS
HIGH PRESS AIR
DAMPER OPERATOR
CGB-136

3. Remove cover from controller.

4. Apply 20 psi supply pressure.

PART II

Operation

1. Turn the fan, a/c and heater switches ON.

2. Observe the branch line gage.

   a. Did the pressure increase or decrease? ____________________

   b. Is the controller direct or reverse action? ____________ action.

   c. How can its action be changed? ____________________

   ____

8B- 75-625

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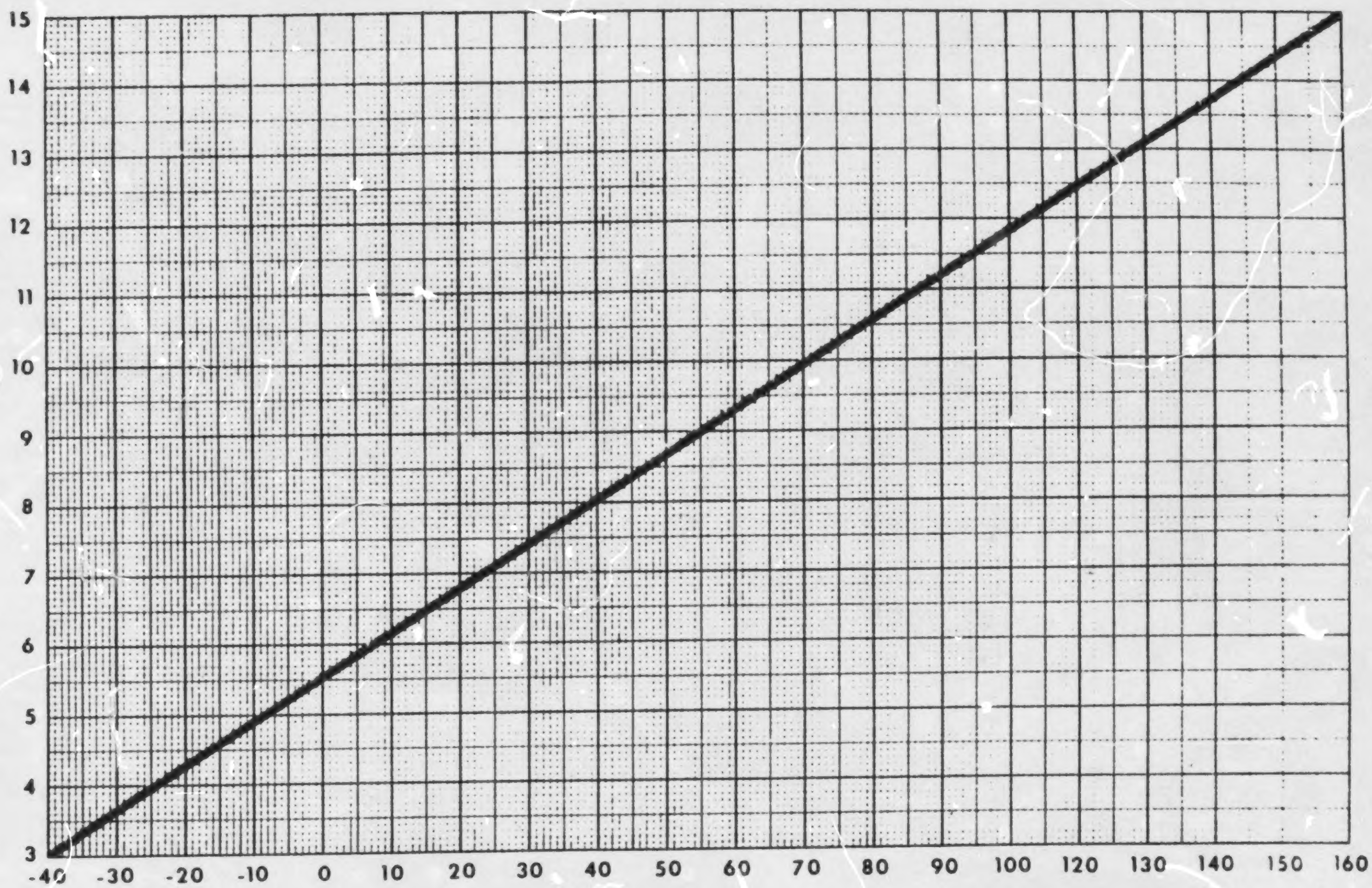

Pneumatic Temperature Chart

d. Find the ambient temperature of the sensor.

Sensor temperature ________________ °F.

e. Using the pneumatic temperature chart that follows, what pressure should Port No. 1 be indicating? ________________

3. Turn the heater, fan and a/c switches OFF and allow the temperature at the sensor to stabilize.

PART III

CALIBRATION

1. Determine the action

a. For what action is the controller set? ________________

b. How can the action be changed? ________________

____

2. Set the controller for direct action.

NOTE: The two action springs are left disconnected when controller is adjusted for direct action. Springs are connected for reverse action.

3. Adjust the proportional band setting for 10 percent P. B.

NOTE: The main lever which has the P. B. adjustment knob has two P. B. scales. One scale is for direct action and the other for reverse action. When adjusting this setting, be sure the proper scale is used for the action the controller is set for.

When the P. B. setting is 10 percent, what is the throttling range of this controller, having a 50 to 100°F range? ________________ °F

4. Check the proportional band spring.

NOTE: This spring is connected to the main lever when the proportional band setting is 15 percent and above.

With a proportional band setting of 10 percent is this spring connected?

____

5. Turn the set point adjusting screw to obtain 8 psi branch line pressure.

NOTE: In the field, the branch line pressure would be adjusted to the mid-spring range of the control device.

PART IV

PROPORTIONAL BAND CHECK

1. Turn the set point adjusting screw until 3 psi branch line pressure is obtained.
2. Note the temperature setting on dial. ____________________ °F.
3. Now, turn the set point adjusting screw until 13 psi branch line pressure is obtained.
4. Note the temperature setting on dial.

   Temperature setting ____________________ °F.

   NOTE: The temperature setting difference obtained with a 3-13 psi branch line pressure change should equal the proportional band setting. (Refer to answer of question 3 under calibration.)
5. If the proportional band setting is not correct, then readjust P.B. and recalibrate controller following calibration step procedure.
6. If the above check indicates correct adjustment, the pneumatic controller is in calibration.
7. Turn the set point adjustment to a desired set point value, and the pneumatic sensor-controller will be in control.

Approved by ______________________________
(Instructor)

Department of Civil Engineering Training
Sheppard Air Force Base, Texas

WB 3AZR54550-2-III-4-P5

TROUBLESHOOTING ABSORPTION SYSTEMS

OBJECTIVE

Upon completion of this project you will be able to:

1. Use a lithium bromide troubleshooting chart.
2. Identify conditions, causes, and remedies of absorption unit malfunctions.

Standard of performance

The standard of performance for this project is 100 percent completion, errorfree.

EQUIPMENT

	Basis of Issue
WB 3AZR54550-2-III-4-P5	1/student
Pen or pencil	1/student

PROCEDURE

1. Refer to the troubleshooting chart that follows and complete the statements.
2. Each manufacturer of absorption systems publishes an aid to problem solving.

   This aid is a ______________________________
3. Troubleshooting charts are usually divided into three columns. These columns are labeled:

   a. ______________________________

   b. ______________________________

   c. ______________________________
4. An improperly set capacity control valve can result in the condition called

   ____
5. Solidification during operation can happen on absorption systems because of

   ____________________ at the solution pumps.
6. Air inside the machine can result in two conditions. These two conditions are

   ____________________ and ____________________

7. A unit solidified at startup because of excess steam pressure. The recommended remedy is to

8. A machine solidified during operation because the cooling tower water was too cold. The suggested remedy is ____________________________

9. Electrical power was lost just as the dilution cycle was started and the solution crystallized in the heat exchanger. The cause of solidification according to the Troubleshooting Chart is ____________________________

____

Checked by ________________________
(Instructor)

Low capacity	1.	Improper refrigerant charge.	Check overflow tube. Remove refrigerant.
	2.	Air in machine.	Find leak and repair. Purge the machine.
	3.	Solution leaving generator below 220°F at full load.	Raise steam pressure. Unplug steam strainer.
	4.	Capacity control valve improperly set.	Reset capacity control valve to design temperature.
	5.	Improper purging.	Check operation of the purge unit.
	6.	Condenser water temperature too high or small condenser waterflow.	Reset tower bypass control. Check pump operation.
Solution solidifies at startup.	1.	Improper purging.	Check purge operation.
	2.	Cooling tower water too cold.	Reset cooling tower bypass valve to design temperatures.
	3.	Excess steam pressure.	Reset steam regulating valve.
	4.	Air inside machine.	Purge the machine.
	5. .	Poor wetting of absorber tubes.	Add alcohol
Crystallization of Lithium Bromide solution during operation.	1.	Air leakage.	Check unit for leaks.
	2.	Seal leakage.	Close seal tank makeup valve. Check seal tank for water loss.
	3.	Steam pressure high.	Reset to design.
	4.	Condenser water too cold.	Check and reset cooling tower bypass valve.
	5.	Dilution cycle less than seven minutes.	Lengthen dilution cycle. Desolidify.

Troubleshooting Chart

ABSORPTION SYSTEM TROUBLES

In this discussion of absorption machine problems, we will limit the coverage to the most common areas. Crystallization (solidification) will take up the major portion of this subject since several common absorption machine problems result in the absorbent solidifying. See figure 112

Power Failure

When a power failure occurs, the machine pumps stop which set up the condition necessary for crystallization. The power failure prevents the machine from going through a normal dilution cycle. The dilution cycle is a sequence which mixes the weak absorbent solution with the concentrated absorbent solution. This mixture produces a concentration that will not crystallize at room temperature. Without the dilution cycle, the concentrated solution will cool and crystallize at approximately 100°F.

Condenser Water

Condenser water is the water coming from the cooling tower. It enters the system at the absorber. A drop in this water temperature below its normal 85°F can cause the strong solution to solidify in the heat exchanger. Should the water temperature drop from 85°F to 55°F, the temperature of the diluted solution going through the heat exchanger would be too cool. This would reduce the temperature of the strong solution leaving the heat exchanger to approximately 100°F, thus causing the solution to begin solidifying. Accurate control is very important for condenser water. A malfunction in this system will cause not only crystallization but also loss of system efficiency.

ABSORPTION TROUBLESHOOTING CHART

PROBLEMS	CAUSE	REMEDY
1. Lithium bromide solidifies at startup	a. Condenser water below designed temperature.	a. Reset tower water bypass valve.
	b. Air in machine.	b. Purge system.
	c. Steam pressure too high	c. Reset pressure regulating valve.
2. Lithium-bromide solidifies during operation.	a. Condenser water below design temperature.	a. Reset tower water bypass valve.
	b. Improper purging.	b. Check purge system.
	c. Salt buildup on absorber tubes and spray nozzles.	c. Add octyl alcohol.

PROBLEMS	CAUSE	REMEDY
3. Low capacity.	a. Air in machine.	a. Repair leak and/or purge system.
	b. Scale in condenser tubes.	b. Remove scale and treat water.
	c. Not enough solution concentration in generator.	c. Check amount of steam flow and pressure.
	d. Refrigerant overflow from condenser to evaporator	d. Remove part of refrigerant charge.
	e. Capacity control valve returning too much weak solution back to absorber.	e. Reset control to correct temperature.
4. Machine shuts down on safety controls.	a. Motor overload opens.	a. Find reason and reset overload.
	b. Low refrigerant temperature.	b. Check temperature controller. Reset if needed.
5. Solidification during shutdown.	a. Dilution cycle not long enough.	a. Lengthen dilution cycle to at least 7 minutes.
	b. No load when diluting	b. Open reclaiming valve to put load on machine.
6. Air leak into machine.	a. Any connection, fitting, or component exposed to atmosphere may be cause.	a. (1) Perform leak check. (2) Check vertical purge.
7. Loss of vacuum at shutdown.	a. Air leakage into machine.	a. (1) Check for leakage at valves. (2) Perform leak check.
8. Failure to keep machine purged.	a. Air leakage into machine.	a. Perform leak check.
	b. Vertical purge not removing noncondensables properly.	b. (1) Check rate of purge. (2) Purge solution solidified. Desolidify.

Figure 11 2 Troubleshooting Chart

SUMMARY

The absorption system operates on the principle of one material being able to absorb or take up the vapors of another substance and thus reduce the pressure.

The absorption refrigeration unit consists of a generator assembly and an absorber assembly. The condenser and generator are combined in the generator assembly, or upper shell of the unit; while the evaporator and absorber are combined in the absorber assembly, or lower shell of the unit. The control panel is located on the side of the absorber assembly. The other minor units, such as the absorber sight glass, solution heat exchanger, and the solution pump are usually mounted between the supporting legs of the absorption unit.

Air leakage into the machine is the cause of many troubles. It will cause decreased refrigeration effect and crystallization of the lithium bromide solution. Some other troubles that you will encounter is with controls, improper setting of valves and system temperatures not within operating range.

This system is used for air-conditioning and industrial process cooling. The evaporator design temperature is normally 38°F. These units are made in a wide range of sizes, varying from 3 to over 1000 tons.

REFERENCES

Textbook; Modern Refrigeration and Air Conditioning, Althouse, Turnquist, Bracciano

Manual; York, Absorption Systems, Operation, Service, and Maintenance

ATC-SHEPPARD AFB TEX. 74-729